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MICROBIAL DEGRADATION/ALTERATION OF CARBONACEOUS SPECIES IN CANADIAN ORES AND CONCENTRATES - PHASE II

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TABLE OF CONTENTS

		Page
1.0	SUMMARY	1
2.0	INTRODUCTION	6
3.0	BACKGROUND	7
4.0	EXPERIMENTAL	9
	4.1 Materials	9
	4.2 Enrichment of Hydrocarbon Degrading Microorganisms	9
	4.3 Bacterial Growth Rate Studies	12
	4.3.1 Reactor Design	12
	4.3.2 Growth Rate Determinations	12
	4.3.3 Process Water Detoxification	15
	4.4 Continuous Bio-Treatment of Concentrate	16
	4.4.1 Bench Scale Reactor Tests (3 L)	16
	4.4.2 Pilot Scale Reactor Test (16 L)	17
	4.5 Separation of Refractory Hydrocarbon	17
	4.5.1 Hydraulic Elution	19
	4.5.2 Heavy Liquid Separation	21
	4.5.3 Flotation	21
	4.5.4 Cycloning	22
	4.6 Mineralogical Examination	24
5.0	RESULTS AND DISCUSSION	25
	5.1 Bacterial Growth Rates	25
	5.2 Continuous Bio-Treatment Performance	29
	5.2.1 Bench Scale Reactor Tests (3 L)	29
	5.2.2 Pilot Scale Reactor Test (16 L)	38
	5.3 Hydrocarbon Separation	41
	5.3.1 Hydraulic Elution	41
	5.3.2 Heavy Liquid Separation	43
	5.3.3 Flotation	44
	5.3.4 Cycloning	49
	5.4 Mineralogical Examination	51
	5.4.1 Wet Mounts	51
	5.4.2 Polished Thin Sections	51

TABLE OF CONTENTS (Cont'd)

		Page
6.0	ECONOMIC FEASIBILITY	57
	6.1 Process Description	57
	6.2 Operating Costs	60
	6.3 Feasibility Assessment	63
7.0	CONCLUSIONS AND RECOMMENDATIONS	65
8.0	ACKNOWLEDGEMENTS	70

APPENDIX I	BACTERIAL GROWTH CURVES
APPENDIX II	METHOD FOR ORGANIC CARBON DETERMINATION
APPRENDIX III	EXPERIMENTAL WORK PROGRAM: CONTINUOUS BIO-TREATMENT OF MOLYBDENITE CONCENTRATE IN A 3 L AIR LIFT REACTOR
APPENDIX IV	FLOTATION TEST DATA

LIST OF TABLES

		Page No.
TABLE 1	Analysis of Molybdenum Concentrate Composite	10
TABLE 2	Analysis of Flotation Plant Process Water	10
TABLE 3	Nutrient Formula Used for Bacterial Enrichment	11
TABLE 4	Free Settling Velocities of Molybdenite and Hydrocarbon Particles in Water	20
TABLE 5	Summary of Bacterial Growth Rate Data	26
TABLE 6	Summary Data from Continuous 3 L Reactor Tests	30
TABLE 7	Analysis of Plant Process Water Before and After Detoxification Tests	32
TABLE 8	Summary Data from Continuous 16 L Reactor Test	40
TABLE 9	Hydraulic Elution Test Data	42
TABLE 10	Heavy Liquid Separation Data	45
TABLE 11	Flotation Test Summary	46
TABLE 12	Cycloning Test Summary	50

LIST OF FIGURES

		Page
FIGURE 1	Schematic of Continuous Bio-treatment System	13
FIGURE 2	Design and Dimensions of 16 L Air Lift Reactor	18
FIGURE 3	Example Bacterial Growth Curve	27
FIGURE 4	Bacterial Populations and Feed Rates from 3 L Bio-treatment Experiment #1	33
FIGURE 5	Bacterial Populations and Feed Rates from 3 L Bio-treatment Experiment #2	35
FIGURES 6	Bacterial Populations and Feed Rates from 3 L Bio-treatment Experiment #3	37
FIGURE 7	Bacterial Populations and Feed Rates from 16 L Bio-treatment Test	39
FIGURE 8	Photomicrograph of Untreated Concentrate - Wet Mount	53
FIGURE 9	Photomicrograph of Uninoculated Control Concentrate - Wet Mount	53
FIGURE 10	Photomicrograph of Bacterially Treated Conctentrat - Wet Mount	54
FIGURE 11	Photomicrograph of Untreated Concentrate - Polished Section	54
FIGURE 12	Photomicrograph of Treated Concentrate - Polished Section	55
FIGURE 13	Photomicrograph of Molybdenite-Hydrocarbon Associations in Untreated Concentrate - Polished Section	55
FIGURE 14	Photomicrograph of Hydrocarbon Particle in Treated Concentrate - Polished Section	56
FIGURE 15	Photomicrograph of Reactor Overflow Solids - Polished Section	56
FIGURE 16	Bio-treatment Plant Flowsheet	58

1.0 SUMMARY

The flotation circuit of a major Canadian molybdenum and copper producer is occasionally plagued by the presence of a natural hydrocarbon (gilsonite) in the ore feed. The hydrocarbon is "sticky" or asphalt-like and adheres to mineral surfaces indiscriminately, causing particle agglomeration. This dilutes the molybdenum product grade and can result in unsaleable product. To date, no metallurgical process has been able to economically remove the hydrocarbon.

Bacterial degradation of the hydrocarbon has been advocated as a potential method to upgrade contaminated molybdenum concentrate. A Phase I program has been completed which isolated microorganisms capable of degrading the hydrocarbon species. This report presents the findings of a Phase II experimental program. The scope of this program was to optimize the process parameters for bacterial growth, to bio-treat concentrate under continuous nutrient flow conditions, and to separate the molybdenum and hydrocarbon minerals from bio-treated residues.

Dry contaminated concentrate was slurried in tap water and inoculated with bacteria. Growth rate studies were conducted over a wide range of process conditions and nutrient compositions. A nutrient formula was determined which maximized bacterial growth for a minimal addition of nutrients. This optimal formula contained:

- $(NH_4)_2SO_4$ - 0.2 g/L
- KH_2PO_4 - 0.07 g/L
- Yeast extract - 0.07 g/L

This yielded an average bacterial doubling time of 71 minutes at 20°C, pH 7.0 and 20% solids. Bacterial growth was not sensitive to pH in the range 6.0 to 8.0, or to temperature in the range 18 to 30°C.

Bacterial growth rates were much lower (308 min. doubling time) in slurries prepared with plant process water. This was attributed to the presence of toxic species in the process water, such as CN^-, S^{2-}, Mo and Cu. Continued acclimation work could yield bacterial strains which have higher growth rates in this medium. Failing this, in practice the concentrate froth could be filtered and repulped in fresh water to reduce the concentration of toxic species. The addition of $FeCl_3$ to precipitate CN^- and S^{2-} species has also shown merit. To ensure demonstration of the bio-treatment concept, all subsequent testwork was conducted using tap water for concentrate slurrying.

Continuous concentrate processing (batch solids) using 3 L and 16 L air-lift reactors allowed bacterial treatment to proceed vigorously for a two to three day period. At this point, up to 3.8% of the initial benzene soluble or "sticky" fraction of the hydrocarbon was removed from the feed. By comparison, there was only 0.3% removal in an uninoculated control test. About 6% of the feed solids reported to the reactor overflow with the continuous decant solution. There was an increase in the hydrocarbon/molybdenum ratio in the bio-treated overflow solids compared to both the fresh feed and the uninoculated control.

Protozoal contamination was consistently experienced after several days operation of the continuous bio-treatment tests. The predominant organism was Cyathomonas sp. Protozoa

ingested the hydrocarbon degrading bacteria, and the consequent proliferation of this contaminating organism forced a halt to experimentation. In future work, protozoal growth may be limited by operating at higher pH (8.0 to 8.5) or by using antiprotozoal agents. This will allow increased bio-treatment time and thereby increase the extent of hydrocarbon degradation and subsequent removal.

The following metallurgical techniques were used to evaluate hydrocarbon-molybdenite separation in bio-treated and untreated concentrates: hydraulic elution, flotation, heavy liquid separation and cycloning. Results showed that hydraulic elution and flotation were not effective in separating hydrocarbon from molybdenite. Heavy liquid separation and cycloning gave more favourable responses.

Heavy liquid separation of bio-treated residue using an aqueous Na_2SO_4 solution (S.G. 1.23) yielded clean hydrocarbon float products (> 69.5% C) with minimal molybdenum contamination (< 0.25% Mo). Bacterial treatment increased the extent of carbon removal in these tests from 18.8 wt.% C (untreated concentrate) to 24.0 wt.% C (treated concentrate).

Cycloning was the most effective method investigated for removing hydrocarbon from concentrate; however, molybdenum losses to the overflow were excessive. Bacterial treatment increased the extent of carbon rejection from 69.3 wt.% C (untreated concentrate) to 74.5 wt.% C (treated concentrate).

Future testwork should be aimed at optimizing the cycloning or heavy liquid separation of concentrate which has been bio-treated to a greater extent. Cycloning in heavy liquid medium could be a promising technique.

Microscopic examination of wet mounts revealed that untreated concentrate particles tended to agglomerate. However, mounts with treated concentrate showed that most of the particles were separate. This difference in particle dispersion has been attributed to bacterial surfactants and/or surface oxidation of hydrocarbon. Isolation and characterization of the microbial surfactants would be of interest.

Examination of polished thin sections of concentrate showed an abundance of molybdenite slimes (<10 microns in diameter), which in many instances coated the surface of much larger hydrocarbon particles. Bacterial treatment greatly reduced this coating phenomenon.

It is suspected that the presence of molybdenite slimes in the concentrate adversely affected the performance of metallurgical separations. These slimes would contribute to poor flotation selectivity and to high molybdenum losses to cyclone overflow, irrespective of bacterial treatment. Some lab-scale separation tests should be performed on deslimed material (+400 mesh). From a fundamental viewpoint, this would clarify the effect of bacterial treatment on mineral separability.

While realizing that much development and optimization work remains to be done, the operating cost for concentrate bio-treatment was estimated to indicate the economic feasibility of the process concept. This cost for a four-day batch (solids) bio-treatment process was $235/tonne concentrate. The highest cost components were yeast extract nutrient, and compressed air for reactor aeration and agitation. It is projected that operating costs can be decreased substantially by negotiating a contract to use commercially available organic waste materials as a source of nutrient. Potential sources are spent brewery yeast, corn steep liquor, or distillery wastes. Optimizing the reactor design and operation would also contribute to major savings.

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The potential value of MoS_2 contained in the bio-treatment feed concentrate is in the order of $880/tonne. Thus, if bio-treatment can consistently result in a saleable grade molybdenum product, the maximum incremental operating cost of $235/tonne is considered within reason. This cost differential is the incentive to continue research and process development on the microbial degradation of hydrocarbon.

1.0 SOMMAIRE

Le circuit de flottation d'un important producteur canadien de molybdène et de cuivre est occasionnellement perturbé par la présence d'un hydrocarbure naturel (gilsonite) dans le minerai traité. Cet hydrocarbure est collant, ou similaire à l'asphalte, et il adhère sans discrimination aux surfaces des minéraux, ce qui provoque une agglomération des particules. Ceci dilue la teneur du minerai de molybdène et peut conduire à un produit invendable. Jusqu'à ce jour, aucun processus métallurgique n'a permis d'éliminer l'hydrocarbure de manière économique.

On a suggéré la dégradation bactérienne de l'hydrocarbure comme une méthode potentielle de valorisation d'un concentré de molybdène contaminé. On a exécuté la phase I d'un programme qui a permis d'isoler des micro-organismes capables de dégrader l'hydrocarbure. On présente dans ce rapport les résultats d'un programme expérimental, phase II. L'objectif de ce programme était l'optimisation des paramètres du processus permettant le développement bactérien pour le bio-traitement de concentrés dans des conditions d'écoulement continu d'agents nutritifs, et la séparation du molybdène et des hydrocarbures des résidus du traitement biologique.

Le concentré contaminé sec a été transformé par addition d'eau (eau du robinet) en une boue qu'on a ensemencée de bactéries. On a déterminé le taux de développement dans une vaste gamme de conditions de traitement et de compositions du milieu nutritif. On a déterminé une formule de milieu nutritif qui maximise le développement bactérien avec addition minimum de composés nutritifs. La composition optimale du milieu est la suivante:

- $(NH_4)_2SO_4$ - 0,2 g/L
- KH_2PO_4 - 0,07 g/L
- Extrait de levure - 0,07 g/L

Dans ces conditions, le nombre moyen de bactéries doublait en 71 minutes dans les conditions suivantes: 20°C, pH 7, 20% de solides. Le développement bactérien n'était pas sensible au pH entre pH 6 et pH 8, ni à la température entre 18 et 32°C.

Les taux de développement bactérien étaient beaucoup plus faibles (doublement en 308 minutes) dans les boues préparées avec l'eau utilisée dans les opérations de traitement de l'usine. On a imputé ces résultats à la présence d'ions toxiques dans l'eau de traitement, comme CN^-, S^{2-}, Mo et Cu. La poursuite de travaux d'acclimatation pourrait produire des variétés de bactéries manifestant un taux de reproduction plus élevé dans un tel milieu. À défaut, on pourrait filtrer l'écume de concentré et la repulper avec de l'eau propre pour réduire la concentration des espèces toxiques. L'addition de $FeCl_3$ pour précipiter CN^- et S^{2-} semble également présenter un certain potentiel. Pour garantir la démonstration du concept du traitement biologique, on a employé l'eau du robinet pour la formation des boues de concentré pour tous les essais ultérieurs.

Le traitement continu de concentré (lots successifs de solides) avec des réacteurs à air de 3 L et de 16 L, a permis au traitement bactérien de se dérouler vigoureusement pendant une période de trois jours. À ce stade, jusqu'à 3,8% de la quantité initiale de benzène soluble, ou fraction "collante" de l'hydrocarbure, étaient éliminés du matériau traité. Par comparaison, le taux d'enlèvement n'était que de 0,3% dans les essais de contrôle sans ensemencement. On a récupéré environ 6% des solides introduits dans le courant du trop-plein du réacteur

avec la solution de décantage continu. Il y a eu une augmentation du rapport hydrocarbure-molybdène dans les solides du courant du trop-plein après traitement biologique, par comparaison au rapport existant dans la boue d'origine et dans la boue de contrôle sans ensemencement.

On a constamment observé une contamination par les protozaires après plusieurs jours de déroulement des essais de traitement biologique continu. L'organisme prédominant était le Cyathomonas sp. Protozoa, qui ingérait les bactéries responsables de la dégradation des hydrocarbures, et de ce fait la prolifération de cet organisme contaminant entraînait l'arrêt de l'expérience. Dans les travaux ultérieurs, on pourrait limiter la croissance des protozaires en travaillant à un pH plus élevé (8 à 8,5) ou en utilisant des agents anti-protozaires. Ceci permettra une augmentation du temps de traitement biologique, et augmentera par conséquent le degré de dégradation des hydrocarbures et leur élimination.

On a utilisé les techniques métallurgiques suivantes pour évaluer la séparation hydrocarbure-molybdènite dans les concentrés non traités et les concentrés qui ont subi le traitement biologique: élution hydraulique, flottation, séparation gravimétrique par liquide dense, et séparation en cyclone. Les résultats ont indiqué que l'élution hydraulique et la flottation ne permettaient pas de séparer efficacement les hydrocarbures de la molybdènite. La séparation gravimétrique par liquide dense et en cyclone a donné de meilleurs résultats.

Les essais de séparation gravimétrique par liquide dense sur les résidus de traitement biologique, avec une solution aqueuse de Na_2SO_4 (densité 1,23) produisait un hydrocarbure flottant propre (plus de 69,5% C) avec contamination minime

par le molybdène (moins de 0,25% Mo). Le traitement bactérien augmentait le taux d'enlèvement du carbone dans ces tests, de 18,8% C (en poids) (concentré non traité) à 24% C (en poids) (concentré traité).

Parmi les méthodes évaluées, le traitement au cyclone s'est révélé le plus efficace pour la séparation des hydrocarbures du concentré; cependant, les pertes de molybdène au cours de trop-plein étaient excessives. Le traitement bactérien augmentait le taux de réjection du carbone de 69,3% C (en poids) (concentré non traité) à 74,5% C (en poids) (concentré traité).

L'objectif des travaux ultérieurs devrait être l'optimisation de la séparation par cyclone ou liquide dense, sur un concentré qui aura subi un traitement biologique plus poussé. Le passage en cyclone dans un milieu liquide dense pourrait être une technique prometteuse.

L'examen au microscope de lames humides a indiqué que les particules de concentré non traité tendaient à s'agglomérer. Cependant, on observait sur les lames de concentré traité que la plupart des particules étaient séparées. Cette différence quant à la dispersion des partticules a été imputée à des agents surfactants bactériens et/ou à l'oxydation superficielle de l'hydrocarbure. Il serait intéressant d'isoler et d'identifier les surfactants microbiens.

L'examen de sections minces polies de concentré a révélé une abondance de particules fines de molybdènite (moins de 10 microns de diamètre) qui, dans de nombreux cas, recouvraient les surfaces de particules d'hydrocarbure beaucoup plus grandes. Le traitement bactérien réduisait considérablement ce phénomène de revêtement.

On soupçonre que la présence de fines particules de molybdènite dans le concentré affecte négativement la performance des opérations de séparation métallurgique. Ces particules fines pourraient contribuer à l'insuffisance de sélectivité lors de la flottation et à l'importance des pertes de molybdène vers le trop-plein du cyclone, quel que soit le traitement bactérien. On devrait exécuter quelques essais de séparation en laboratoire sur un matériau dont on aurait éliminé les particules fines (+400 mesh). Du point de vue fondamental, ceci clarifierait les effets du traitement bactérien sur les caractéristiques de séparation du composé minéral.

Bien qu'on sache qu'il y a encore beaucoup de travail de mise au point et d'optimisation à faire, on a estimé les frais d'exploitation du traitement biologique du concentré pour déterminer la factibilité économique du concept du procédé. Pour un processus de traitement biologique de 4 jours par lot (solides) ce coût était de 235 $ par tonne de concentré. Les composants les plus coûteux étaient l'extrait de levure utilisé dans la solution nutritive, et l'air comprimé utilisé pour l'agitation et l'aération du réacteur. On prévoit qu'il serait possible de réduire substantiellement les frais d'exploitation en négociant un contrat pour l'emploi de rebuts organiques disponibles commercialement comme source de matière nutritive. Les rebuts de levure des brasseries, les rebuts de traitement du maïs, ou les déchets de distillerie sont des sources potentielles. L'optimisation de la conception du réacteur et du processus de traitement pourraient également contribuer à la réalisation d'importantes économies.

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La valeur potentielle du sulfure MoS_2 contenu dans le concentré soumis au traitement biologique est de l'ordre de 880 $ par tonne. Par conséquent, si le traitement biologique peut permettre de produire constamment un concentré de molybdène de valeur commerciale, l'augmentation maximum du coût de production semble raisonnable. Cette différence de coût peut justifier la poursuite des travaux de recherche et la mise au point sur la dégradation microbienne de l'hydrocarbure.

2.0 INTRODUCTION

Upon acceptance of Witteck Proposal No. 148-86 by the Department of Supply and Services, bacterial ore treatment studies and metallurgical separations were completed on a hydrocarbon contaminated molybdenum concentrate.

The objectives of the program were as follows:

- To determine growth rates of a previously acclimated mixed bacterial culture in slurried molybdenum concentrate for a range of physical environments and nutrient concentrations. An optimal nutrient formula and the optimal physical environment was to be established for subsequent concentrate treatment testwork.

- To bacterially treat a hydrocarbon contaminated molybdenum concentration in a batch continuous-decantation mode.

- To assess the effectiveness of carbon-molybdenum separation from bacterially treated concentrate using conventional metallurgical techniques such as hydraulic elution, heavy liquid separation, flotation and cycloning.

- To note any concentrate mineralogical differences due to bacterial treatment.

- To determine the economic viability of bacterial treatment by comparing the incremental operating cost to the incremental sales value.

This report presents the results of the laboratory testwork. The effectiveness of bacterial concentrate treatment will be determined using the metallurgical and mineralogical results. Recommendations for further laboratory evaluation and possible in-plant confirmation will be made.

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3.0 BACKGROUND

A hydrocarbon mineral, identified as gilsonite, contaminates approximately 15% of the ore body of a major Canadian copper-molybdenum producer. This mineral floats naturally with the sulphides in the bulk copper-molybdenum flotation circuit, ultimately contaminating flotation products in the molybdenum separation and cleaning circuits.

A typical molybdenum concentrate during a period of high carbon ore analyzed 28.7% Mo, 32.9% C, 0.41% Cu, and 2.7% Fe. The minimum specification for a saleable product is 40% Mo and less than 1% copper. The solid hydrocarbons are believed to interfere with separation in several ways:

- by absorbing flotation reagents;
- by creating a "sticky" flotation froth which entraps gangue minerals;
- by attachment to the mineral surfaces causing the floatability of both desired and undesired minerals; and
- by floating readily with the molybdenite, thereby diluting the froth grade.

Metallurgical methods such as flotation, tabling and cycloning have been investigated to alleviate the hydrocarbon contamination problem, but without economic success.

Subsequently, biotechnology was examined as a potential solution to this problem. A Phase I program was completed with the key findings as follows:

- A mixed culture of hydrocarbon-oxidizing bacteria acclimated readily to the hydrocarbon species present in the slurried molybdenum concentrate. The mixed culture consisted predominantly of the genus Pseudomonas sp.

- Bacteria stripped asphalt-like hydrocarbon from synthetic tar-sand in shaker-flask experiments.

- Cycloning of bacterially treated concentrates increased carbon rejections compared to plant separation data.

- Bacterial treatment resulted in suspension of ore particles, possibly due to surfactant action.

It was concluded that bacterial treatment of contaminated concentrate may be an economically viable method for removing smeared hydrocarbon and residual flotation reagents, thereby improving the response of subsequent flotation separation. The dispersion of ore particles due to the bacterial treatment would also contribute to improved mineral separation.

4.0 EXPERIMENTAL

4.1 Materials

Molybdenum Concentrate and Mill Reclaim Water

Synthetic 4th cleaner molybdenum concentrate was prepared from mine concentrate samples supplied. The analysis of this composite is presented in Table 1.

Mill process water for growth rate studies was obtained from the molybdenum flotation circuit. An elemental analysis of the process water is listed in Table 2.

Microorganisms

Hydrocarbon degrading microorganisms were acclimated to molybdenum concentrate in a Phase I program. These microorganisms comprised a mixed culture composed primarily of members of the genus Pseudomonas sp.

4.2 Enrichment of Hydrocarbon-Degrading Microorganisms

Hydrocarbon-degrading microorganisms from the Phase I program were enriched by subculturing in aerated 3 L flasks at 10% solids on molybdenum flotation concentrate. The nutrient formula used is presented in Table 3. The enrichment process was broken down into three stages:

Enrichment	Inoculum	Incubation Time
1	10%	7 days
2	10%	72 hours
3	10%	48 hours

Table 1

ANALYSIS OF MOLYBDENUM CONCENTRATE COMPOSITE

Assay, %				
C_{TOT}	C_{ORG}	Mo	Cu	Fe
13.5	3.29	13.90	4.93	7.23

Table 2

ANALYSIS OF FLOTATION PLANT PROCESS WATER

Assay, ppm					
Mo	Cu	CN_{Total}	CN_{Free}	S^{2-}	pH
9.10	61.0	41.6	<0.1	28.80	8.30

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Table 3

NUTRIENT FORMULA USED FOR BACTERIAL ENRICHMENT

	Grams/Litre
Na_2SO_4	2.0
$MgSO_4$	0.2
KH_2PO_4	0.5
NH_4Cl	1.0
KNO_3	2.0
$FeSO_4$	trace
Yeast Extract	1.0

Parameters including pH, Eh and bacterial numbers were monitored on a daily basis to follow the enrichment process. The bacterial solution obtained from enrichment #3 was used as inoculum for the bacterial growth rate studies.

4.3 Bacterial Growth Rate Studies

4.3.1 Reactor Design

Air-lift reactors (3 L) were constructed for bacterial growth rate studies. The reactors were designed so that slurried concentrate could be continuously mixed while maintaining vigorous aeration. The air lift reactor was modified for continuous nutrient decantation by inserting an inverted funnel over the air-lift column. The insertion of the funnel created a quiescent zone at the top section of the reactor, enabling solids-free solution to be decanted. The bulk of the solids remained circulating in the central section of the reactor. Figure 1 illustrates the reactor design and its use for the continuous treatment of solids.

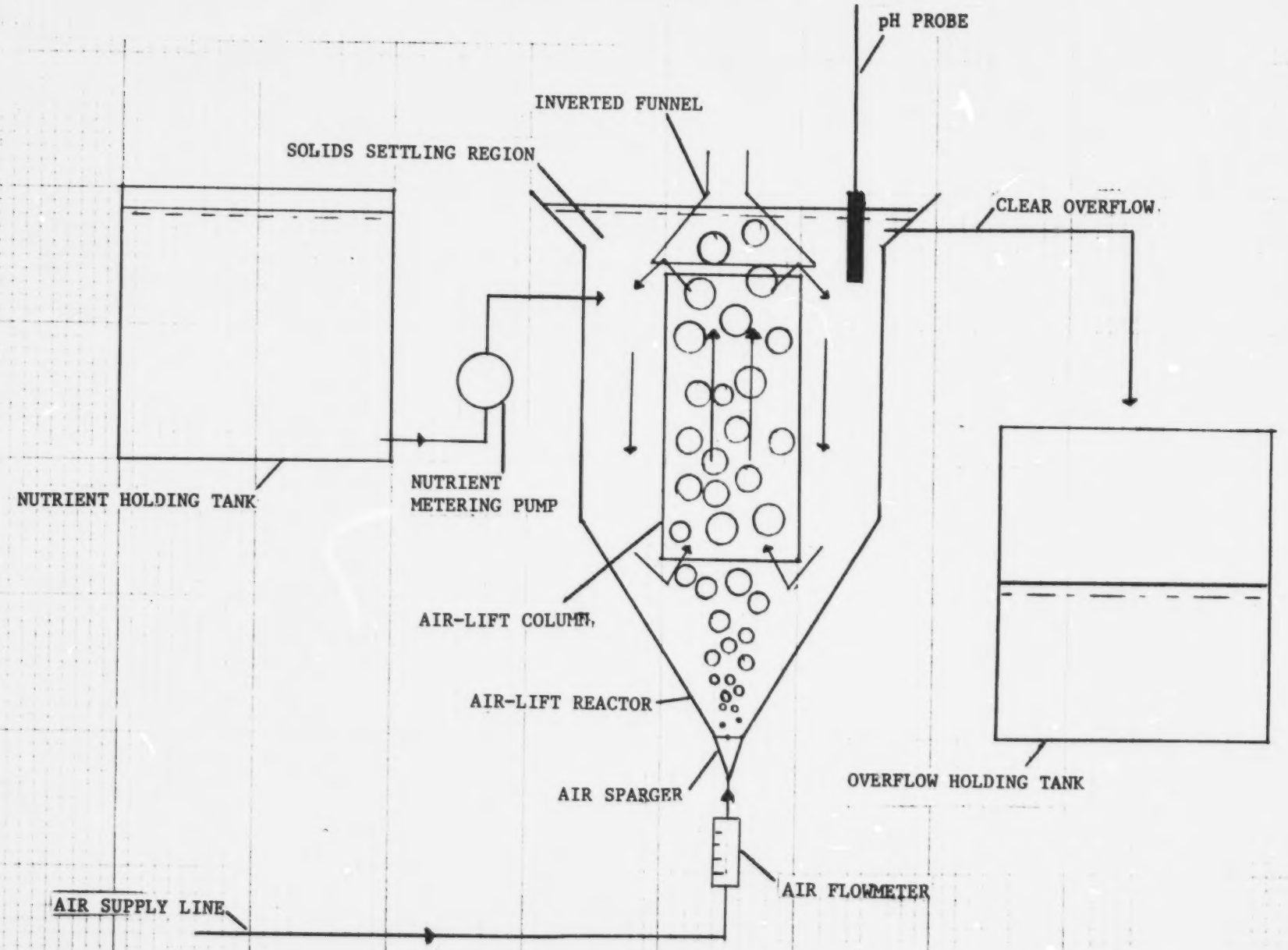
4.3.2 Growth Rate Determinations

Bacterial growth rate studies were performed to assess the effects of lowering nutrient concentrations and varying physical and chemical parameters. The growth rate studies were divided into two separate sections:

1. Initial studies were performed to test the effect of reducing the concentration of nutrients and observing growth rate trends under constant physical and chemical environments; and
2. Once an optimal nutrient formula was determined, further growth rate studies were performed at various temperatures, pH values, pulp densities and chemical environments.

Figure 1

SCHEMATIC OF CONTINUOUS BIO-TREATMENT SYSTEM



Growth rate studies were carried out in 3 L air-lift reactors. For each test, the required weight of solids was added to a 4 L beaker. Tap water of set temperature was added to bring the volume up to 2950 mL. The slurry was agitated vigorously to ensure proper wetting of the solids.

The nutrient constituents were added. The pH was adjusted to the desired level with conc. H_2SO_4 or 1.0 N NaOH. The slurried solution was added to the air-lift reactor. The air was turned on to ensure adequate slurry mixing. The inverted funnel was placed over the reactor.

To start each growth rate experiment, 50 mL of bacterial inoculum was added to the reactor. The reactor contents were mixed for five minutes to ensure homogeneity.

Bacterial populations were measured at the start of each experiment and at hourly intervals using the standard plate count procedure with serial tenfold dilutions on plate count agar. Solids-free solution was prepared for each plate count by removing 10 mL of slurry from the centre of the reactor. The sample was centrifuged at 2800 rpm for 30 seconds to remove suspended solids. The resulting supernatant was assayed for bacterial populations. Duplicate plates were prepared for each bacterial count. Temperature and pH values were monitored on an hourly basis for the duration of the experiments and adjusted when necessary. Bacterial growth rate values were calculated from graphs constructed following data compilation.

4.3.3 Process Water Detoxification

The following tests were conducted to remove toxic elements from molybdenum flotation plant process water.

Filter Cake Repulp

Dry molybdenum concentrate was slurried to 20% solids with reclaim water (114 g conc. plus 455 mL reclaim water). The resultant slurry was agitated for one hour, then filtered through a Buchner funnel with Whatman #3 filter paper. The filter cake was weighed and the moisture content determined. The cake was repulped to 20% solids in tap water. The solids were filtered, weighed, and the moisture content of the cake determined. The resulting filtrate was assayed for CN_{TOT}, CN_F, S^{2-}, Mo, Cu and Fe.

Ferric Chloride Precipitation

Ferric chloride additions (0.125 g, 0.250 g and 0.375 g) were made to 250 mL of reclaim water in separate 400 mL beakers. The resultant solutions were well mixed and allowed to stand for ten minutes. They were then filtered through an 0.45 um Millipore filter. The filtrates were assayed for CN_{TOT}, CN_F, S^{2-}, Mo, Cu and Fe.

4.4 Continuous Bio-Treatment of Concentrate

4.4.1 Bench Scale Reactor Tests (3 L)

Continuous 3 L bio-reactor tests were performed to enable an optimal bacterial population to exist throughout the bio-treatment process. Test products were examined to measure the effects of the bacterial treatment using conventional metallurgical separation methods. Three concentrate treatment tests were performed:

1. Temp. 20°C, 25% solids
2. Temp. 20°C, 20% solids
3. Temp. 30°C, 25% solids

The process flowsheet is illustrated in Figure 1. Nutrient solution was fed into the bioreactor at a predetermined rate from the nutrient holding tank. Bacterial populations were maintained within preset limits by adjusting the nutrient feed pump speed. Spent nutrient solution (containing bacteria and suspended solids) overflowed from the reactor. At the completion of each test, the overflow and reactor solids were dried, weighed and assayed for total carbon, organic carbon and molybdenum. The treated reactor solids were used for subsequent metallurgical tests.

A detailed experimental work program outlining the continuous bio-treatment of concentrate is described in Appendix III.

4.4.2 Pilot Scale Reactor Tests (16 L)

The design and dimensions of the 16 L air-lift reactor are illustrated in Figure 2. A single test was performed to treat five kilograms of molybdenum concentrate. The treated material was used for subsequent cycloning tests. The methods for the setup and operation of the 16 L reactor were similar to those for the 3 L reactor tests, as outlined in Appendix III, with the following exceptions:

1. 170 L of nutrient solution was prepared using the following formula in a clean 45 gallon drum:
   - 20 mL Alkaril $PSMO_{20}$ surfactant
   - 40 g $(NH_4)_2SO_4$
   - 14 g KH_2PO_4
   - 170 L tap water

2. Prepare 2 L of sterile 20 g/L yeast extract in distilled water.

3. Nutrient feed rate was set at 20 to 50 mL/minute.

The addition of surfactant to the nutrient solution was included in this test to aid in the emulsification of hydrocarbon.

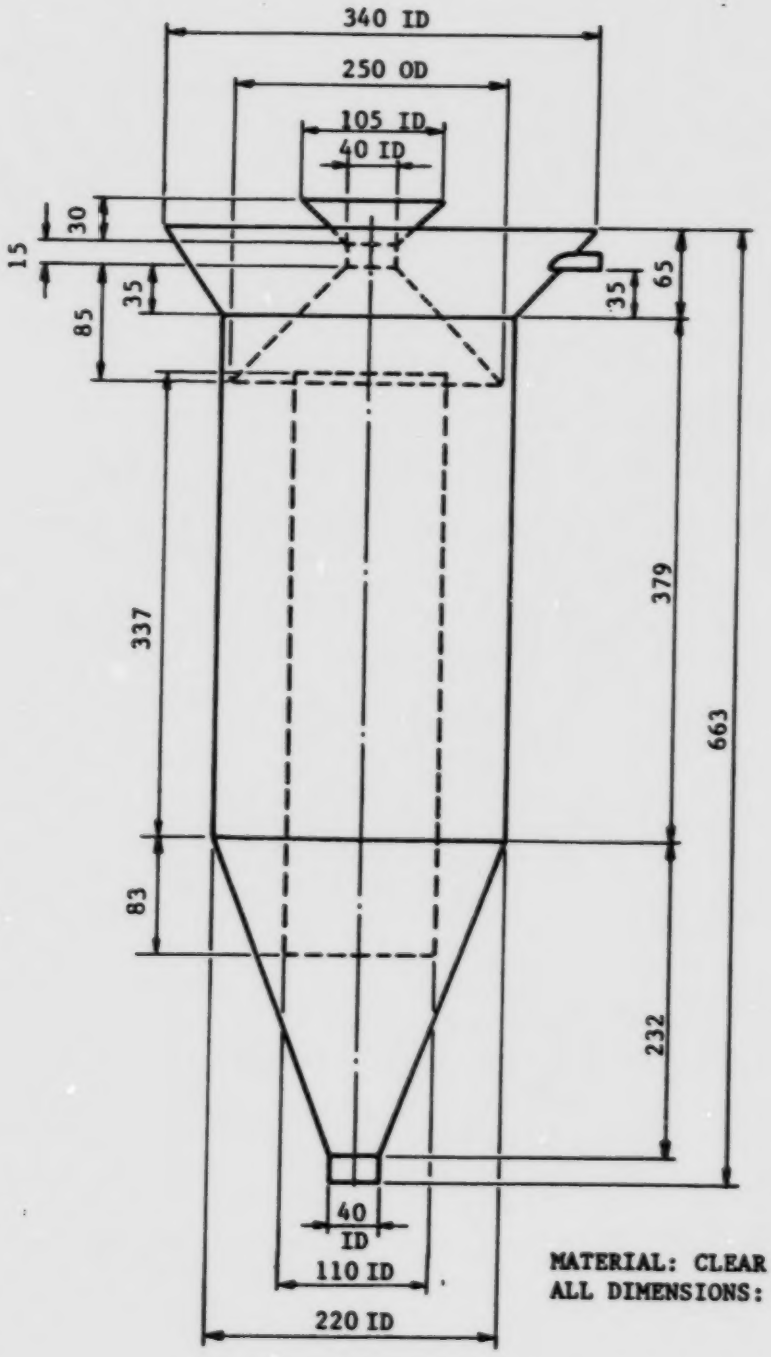
4.5 Separation of Refractory Hydrocarbon

Various metallurgical methods were evaluated on their effectiveness to remove hydrocarbon from treated and untreated molybdenum concentrate. Hydraulic elution, heavy salt separation and cycloning tests were performed to separate molybdenum from hydrocarbon based on their specific gravities.

WD1

FIGURE 2

DESIGN AND DIMENSIONS OF
16 L AIR-LIFT REACTOR



MATERIAL: CLEAR PVC
ALL DIMENSIONS: mm

Flotation tests evaluated the effectiveness of the bacterial treatment on improving hydrocarbon/molybdenite separation efficiencies when using molybdenite depressants or hydrocarbon depressants.

4.5.1 Hydraulic Elution

Hydraulic elution tests were performed to determine if bacterial treatment could improve the separation of hydrocarbon from molybdenite based on differential sedimentation velocity. The settling rates of hydrocarbon and molybdenite in tap water were calculated using the Stokes' equation on the free settling of solids. The specific gravities of molybdenite (4.7) and hydrocarbon (1.2) were known. The minimum particle size was 5 um. Table 4 shows the settling velocities of a number of size ranges of hydrocarbon and molybdenite.

From the dimensions of the decantation vessel (radius = 6.65 cm; height = 16.2 cm; volume = 2.25 L), it was calculated that an elution rate of 30 mL/minute would give a net vertical hydraulic velocity of 2×10^{-2} mm/second. This would allow elution of hydrocarbon particles in the size range 5 to 15 um while molybdenite particles greater than 5 um remained in the vessel.

A slurry of 15% solids (w/v) of flotation concentrate was prepared in the elutriation vessel to a total volume of 2250 mL. The pulp was agitated well to ensure homogeneity. The feed tube to the elutriation vessel was placed approximately 2 cm from the bottom. The agitator was turned off and the pulp stilled with a spatula. The pump was turned on. Decant solutions were collected separately for 2 vessel turnovers, at 2250 mL and 4500 mL. The decant solutions were filtered through

Table 4

FREE SETTLING VELOCITIES OF MOLYBDENITE AND HYDROCARBON PARTICLES IN WATER

Particle Size, microns	Settling Velocity, mm/sec	
	Hydrocarbon	Molybdenite
5.0	2.73×10^{-3}	5.01×10^{-2}
10.0	1.09×10^{-2}	0.200
12.5	-	0.313
15.0	2.46×10^{-2}	0.451
20.0	4.38×10^{-2}	0.802
50.0	0.273	-
100.0	1.09	-

Note:

Calculated using Stokes' Law for water at 20°C. Specific gravities of molybdenite and hydrocarbon assumed to be 4.70 and 1.20, respectively.

1044A

an 0.45 um Millipore filter, dried, weighed and assayed for total carbon and molybdenum. The remaining reactor contents were filtered through a Buchner funnel, dried, weighed and assayed for total carbon and molybdenum. Mass balances and the amounts of carbon and molybdenum removed were calculated.

4.5.2 Heavy Liquid Separation

Centrifugation tests using Na_2SO_4 solution (S.G. 1.23) were carried out to assess the separation/partition of hydrocarbon and molybdenite in the treated versus untreated materials.

A 50 gram sample of concentrate was placed in a glass blender. Hot (70^0C) Na_2SO_4 totalling 250 mL was added. A 0.05 mL aliquot of surfactant $PSMO_{20}$ (Alkaril Chemicals) was added to ensure proper wetting and dispersion of particles. The material was blended for 30 seconds at low speed and then for 30 seconds at high speed. The slurry was de-aerated under vacuum for three minutes. The de-aerated slurry was transferred to centrifuge tubes and centrifuged at 2800 rpm for 5 minutes in a bench-top centrifuge (Dynac #0101). The float and sink products were collected and filtered through 0.45 um Millipore filters. The products were dried, weighed and assayed for total carbon and molybdenum. Product distribution data was calculated.

4.5.3 Flotation

All flotation tests were performed with 200g of concentrate in a 1.5 L flotation cell using a Denver D-12 laboratory flotation machine.

Three flotation schemes were used to assess the improvement in flotation response due to bacterial treatment;

1. Molybdenite depression using ligno-sulphonate Orzan "A"
2. Hydrocarbon depression using Cyanamid Aero Depressant 633
3. Hydrocarbon depression using Cyanamid Aero Depressant 633 plus Alkaril $PSMO_{20}$ surfactant.

For the Orzan "A" flotation tests, the pulp was conditioned to pH 11.9 with lime. The Orzan "A" was added and the pulp conditioned for 5 minutes. Pulling time was 9 minutes.

For the Aero 633 tests, the pulp was conditioned to pH 8.5 with lime. Aero 633 and surfactant were added and the pulp conditioned for 10 minutes. Pulling time was 5 minutes.

The tails and the concentrates were filtered, dried, and weighed. Each product was assayed for molybdenum, carbon, copper and iron.

4.5.4 Cycloning

Cycloning tests were performed to determine if the bacterially treated concentrate prepared in Section 4.2.3.2 would give improved hydrocarbon rejection/molybdenite recoveries compared to the untreated concentrate. It was anticipated that the vigorous forces caused by the cycloning would lead to improved dispersion of particles and thus a better separation. One inch diameter cyclones, from previous in-plant practice were used.

The cyclone was fed in a batch mode using a 4 L autoclave connected to a nitrogen gas source. For each cycloning run, 4 L of a well agitated 15 wt. % slurry of concentrate was fed through the autoclave. The autoclave was sealed and the agitator turned on. The internal autoclave pressure was preset prior to each run. Timed runs for 10 seconds duration were taken. Following each run, the volume of material in the overflow and underflow were recorded. The products were filtered, dried, weighed and assayed for total carbon and molybdenum. Elemental distributions were calculated.

4.6 Mineralogical Examination

Wet mounts of treated and untreated molybdenum concentrate were examined using a binocular microscope. The wet mounts were prepared to examine particle dispersion and the effects caused by bacterial treatment. Mounts were prepared by adding ten grams of solids to 200 mL of deionized water in a glass blender. The material was blended at low speed for one minute. Wet mounts were prepared using glass slides and coverslips. Photomicrographs were taken.

Polished thin sections of treated and untreated material were prepared. Visible alterations between untreated, treated and overflow products were photomicrographed.

5.0 RESULTS AND DISCUSSION

5.1 Bacterial Growth Rates

The results of the growth rate studies are summarized in Table 5. A typical bacterial growth curve is shown in Figure 3. Note the 3 to 4 hour lag period prior to exponential growth. This was found to be typical of most growth rate tests.

The removal of magnesium from the nutrient formula (Expt. 2) did not affect the growth rate. It was assumed that the concentration of magnesium present in tap water was sufficient to permit rapid bacterial growth.

Yeast extract was a necessary constituent of the growth medium. Its removal (Expt. 3) caused a threefold decrease in the bacterial growth rate.

Progressive lowering of ammonium sulphate concentrations were performed to optimize the nutrient formula. The lowest ammonium sulphate concentration enabling rapid bacterial growth was at 0.2 grams/litre (Expt. 7). Further reductions in ammonium sulphate concentrations caused a fall off in the growth rate (Expt. 8).

The nutrient formula used in experiment 7 was determined as the optimal nutrient formula. This formula was used for all subsequent growth rate studies and concentrate treatments.

Bacterial growth rates were not adversely affected in the pH range 6.0 to 8.0 (Expts. 9 and 10). No bacterial growth was observed at pH 9.0 (Expt. 11).

Table 5

SUMMARY OF BACTERIAL GROWTH RATE DATA

EXP'T	pH	Temp °C	% Solids	$(NH_4)_2SO_4$ g/L	Yeast Extract g/L	KH_2PO_4 g/L	$MgSO_4$ g/L	K Value hr. -1	Td Value min.	Comments
1	7.0	20	20	1.5	0.5	0.5	0.1	0.665	90.3	
2	7.0	20	20	1.5	0.5	0.5	-	0.746	80.4	Magnesium not required
3	7.0	20	20	1.5	-	0.5	0.1	0.244	246.0	Yeast extract is required
4	7.0	20	20	0.7	0.23	0.23	-	0.637	94.2	
5	7.0	20	20	0.5	0.16	0.16	-	0.661	90.7	
6	7.0	20	20	0.3	0.10	0.10	-	0.877	68.4	Good growth rate
7	7.0	20	20	0.2	0.07	0.07	-	0.844	71.1	
8	7.0	20	20	0.1	0.04	0.04	-	0.522	115.0	Growth rate fall-off
9	6.0	20	20	0.2	0.07	0.07	-	0.764	78.5	pH 6.0 does not affect rate
10	8.2	20	20	0.2	0.07	0.07	-	1.17	51.3	pH 8.0 does not affect rate
11	9.0	20	20	0.2	0.07	0.07	-	-0.06	-	No growth at pH 9.0
12	7.0	20	25	0.2	0.07	0.07	-	0.642	93.4	
13	7.0	20	30	0.2	0.07	0.07	-	0.682	88.0	High solids does not affect rate
14	7.0	12	20	0.2	0.07	0.07	-	0.093	645.2	Low growth rate at 12°C
15	7.0	30	20	0.2	0.07	0.07	-	1.540	38.8	Very rapid growth rate at 30°C
16 (a)	7.0	20	20 mill reclaim water	0.2	0.07	0.07	-	-	-	No growth due to toxic elements
(b)	7.0	20	20	0.2	0.07	0.07	-	0.195	308.0	Acclimated to reclaim water

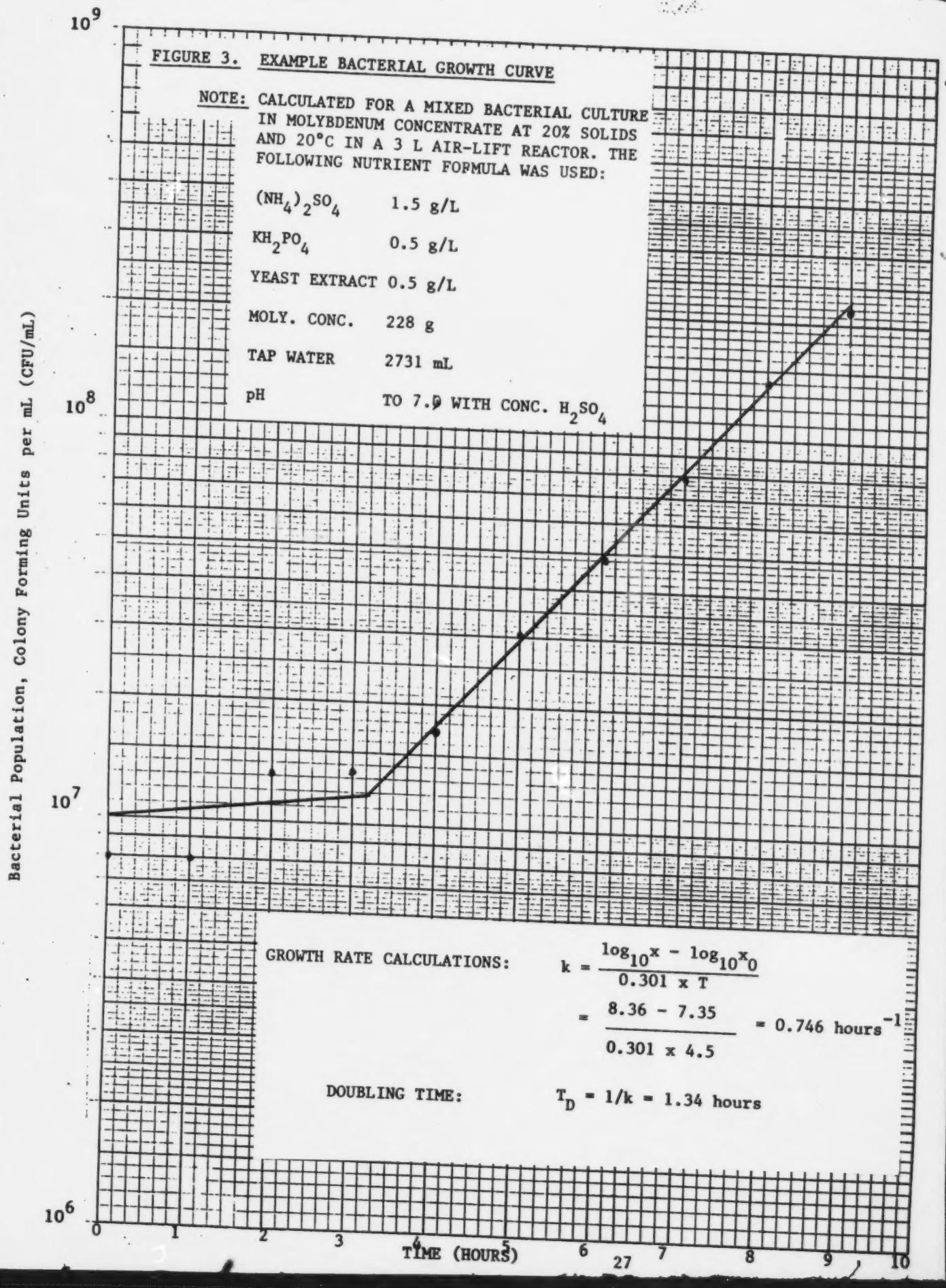


FIGURE 3. EXAMPLE BACTERIAL GROWTH CURVE

NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:

$(NH_4)_2SO_4$	1.5 g/L
KH_2PO_4	0.5 g/L
YEAST EXTRACT	0.5 g/L
MOLY. CONC.	228 g
TAP WATER	2731 mL
pH	TO 7.0 WITH CONC. H_2SO_4

GROWTH RATE CALCULATIONS:

$$k = \frac{\log_{10}x - \log_{10}x_0}{0.301 \times T}$$

$$= \frac{8.36 - 7.35}{0.301 \times 4.5} = 0.746 \text{ hours}^{-1}$$

DOUBLING TIME: $T_D = 1/k = 1.34$ hours

The effect of temperature on growth rate was investigated. At 12°C (Expt. 14), growth rate was slow (k = 0.093 hr^{-1}). At 30°C (Expt. 15), growth rate (k = 1.54 hr^{-1}) was the fastest.

Growth rate experiments performed on molybdenum flotation plant reclaim water did not give a growth rate initially (Expt. 16a), most likely due to toxic elements present. However, acclimation of the bacteria to the reclaim water over a two week period enabled a growth rate of k = 0.195 hr^{-1} to be established (Expt. 16b). It is anticipated that further acclimation work would lead to improved growth rates.

Process water detoxification tests were performed to reduce the levels of toxic elements present. Table 7 presents the solution analyses before and after the detoxification tests.

The filtrate from the filtered and repulped slurry (Test #1) contained less total cyanide by a factor of 8.8. A precipitation test (Test #7) with 0.5 g $FeCl_3$/L process water reduced the total cyanide content by a factor of 4.4.

Both filtering/repulping and $FeCl_2$ precipitation are considered viable process water detoxification methods. However, the fresh water repulp method is the simplest procedure and thus would be recommended for any in-plant trials.

The bacterial growth curves are presented in Appendix I.

1044A

5.2 Continuous Bio-Treatment Performance

Continuous bio-treatment experiments were performed on hyrdrocarbon contaminated molybdenum concentrate to determine any metallurgical improvements effected by bacterial treatment. Data summarizing the bacterial tests are described in Table 6.

5.2.1 Bench Scale Reactor Tests

a) Test #1: 20°C, 25% solids

The experimental results of Test #1 are presented in Figure 4. The results can be summarized as follows:

- Nutrient contamination problems were experienced at hour 25. The yeast extract present in the nutrient solution allowed chance bacterial contaminants to proliferate. Fresh nutrient was prepared immediately. The nutrient became contaminated again at hour 50. Yeast extract concentration was cut back to 0.01 g/L to discourage contaminants.
- Bacterial populations remained constant until hour 75, and then began decreasing.
- Little bacterial activity was evident at hour 79.
- The experiment was terminated at hour 87.
- pH levels remained in the range 7.0 - 7.6.

In subsequent experiments, yeast extract was omitted from the nutrient solution and introduced as a concentrated sterile solution (10 grams/litre). This solution was introduced into the centre of the air-lift reactor at a rate of 0.16 mL/minute.

Table 6

SUMMARY DATA FROM CONTINUOUS 3 L REACTOR TESTS

A) Experiment #1

Total Feed Volume	:	33 L
Duration	:	89 hours
Temperature	:	20°C
Pulp Density	:	25% solids

	Weight of Solids		Assay %			Distribution %		
	grams	Dist.%	C_{TOT}	C_{ORG}	Mo	C_{TOT}	C_{ORG}	Mo
Decant Overflow	34.2	4.05	21.3	4.58	15.2	5.05	6.09	3.53
Reactor Contents	811.3	95.95	16.9	2.90	17.5	94.95	93.91	96.47
Total	845.5	100.00	(17.1)	(3.05)	(17.4)	100.00	100.00	100.00

Organic Carbon Displaced from Feed = 2.30% = (3.05-2.98)/3.05= 2.30%

B) Experiment # 2

Total Feed Volume	:	33 L
Duration	:	112 hours
Temperature	:	20°C
Pulp Density	:	20% Solids

	Weight of Solids		Assay %			Distribution %		
	grams	Dist.%	C_{TOT}	C_{ORG}	Mo	C_{TOT}	C_{ORG}	Mo
Decant Overflow	53.6	7.82	23.9	4.93	15.0	11.09	11.46	6.89
Reactor Contents	632.1	92.18	16.3	3.23	17.2	88.91	88.54	93.11
Total	845.5	100.00	(17.1)	(3.05)	(17.0)	100.00	100.00	100.00

Organic Carbon Displaced From Feed : (3.36 - 3.23)/3.36 = 3.87%

1044A

SUMMARY DATA FROM CONTINUOUS 3 L REACTOR TESTS

C) Experiment #3

Total Feed Volume : 45 L
Duration : 66 Hours
Temperature : 30°C
Pulp Density : 25% Solids

	Weight of Solids		Assay %			Distribution %		
	grams	Dist.%	C_{TOT}	C_{ORG}	Mo	C_{TOT}	C_{ORG}	Mo
Decant Overflow	47.5	5.93	23.5	4.17	16.8	7.68	9.61	5.70
Reactor Contents	754.0	94.07	17.8	2.47	17.5	92.32	90.39	94.30
Total	801.5	100.00	(18.1)	(2.57)	(17.46)	100.00	100.00	100.00

Organic Carbon Displaced from Feed = (2.57-2.47)/2.57 = 3.89%

D) Aqueous Control (Uninoculated)

Total Feed Volume : 35 L
Duration : 100 hours
Temperature : 20°C
Pulp Density : 20% solids

	Weight of Solids		Assay %			Distribution %		
	grams	Dist.%	C_{TOT}	C_{ORG}	Mo	C_{TOT}	C_{ORG}	Mo
Decant Overflow	23.4	2.81	18.5	3.61	17.0	3.05	3.23	2.56
Reactor Contents	809.2	97.19	17.0	3.13	18.7	96.95	96.77	97.44
Total	832.6	100.00	(17.04)	(3.14)	(18.65)	100.00	100.00	100.00

Organic Carbon Displaced from Feed = (3.4-3.13)/3.14 = 0.32%

1044A

Table 7

ANALYSIS OF PLANT RECLAIM WATER BEFORE AND AFTER DETOXIFICATION TESTS

	Solution Analyses, ppm					
	CN_{TOT}	CN_{FREE}	Mo	Cu	Fe	S^{2-}
As-received	41.6	<0.1	9.10	61.0	<0.05	28.80
Repulped Filter Cake(A) (Test #1)	4.7	<0.1	2.45	7.74	<0.05	16.0
$FeCl_3$ Precipitation(B) Filtrate (Test #2)	9.4	<0.1	0.05	9.11	14.5	6.4

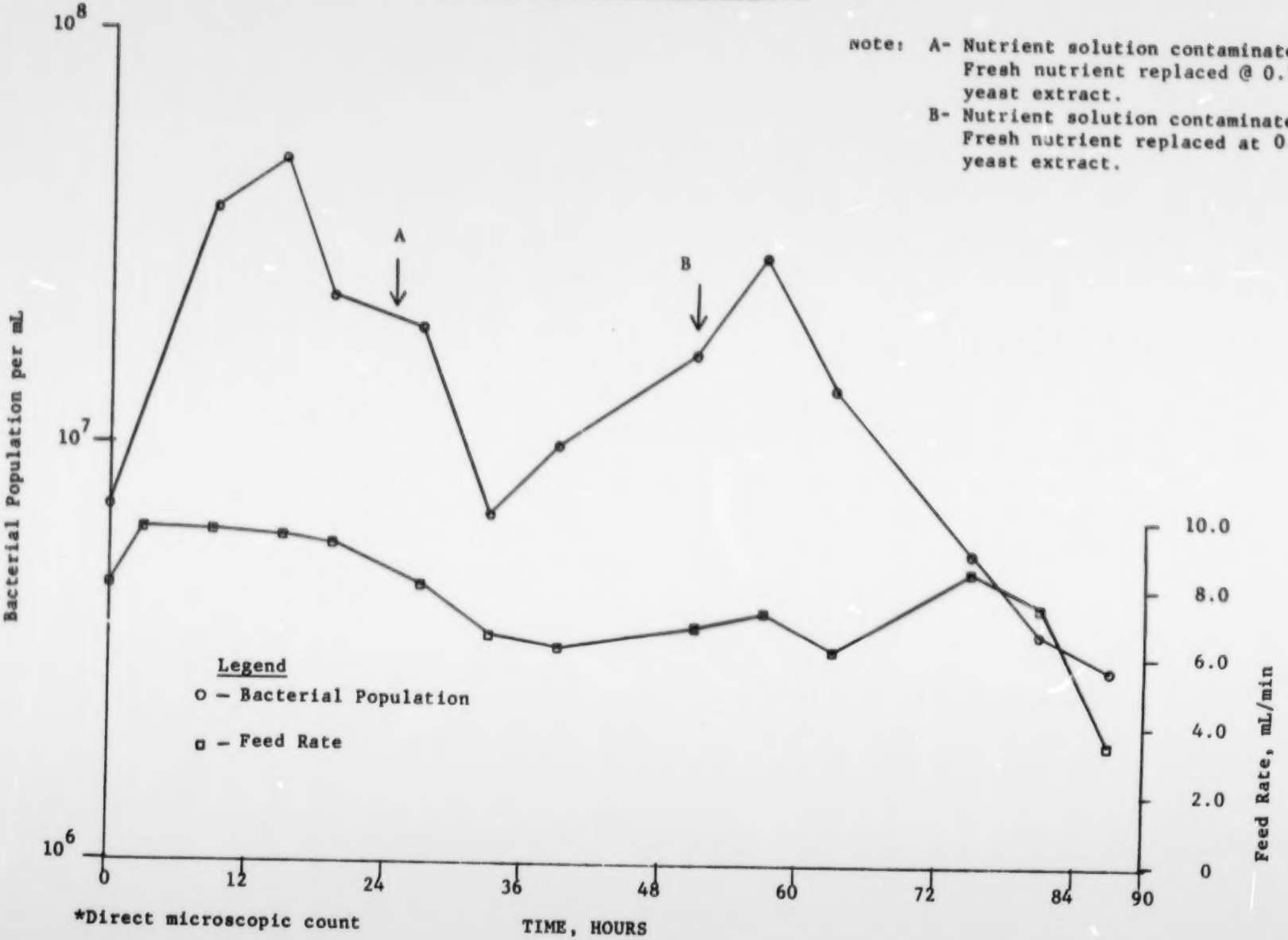
Note A: Filter cake contained 32.7% moisture. This was repulped to 20% solids using tap water.

Note B: Precipitation of solids with 0.5 g $FeCl_3$/L reclaim water.

1044A

Figure 4

BACTERIAL POPULATIONS AND FEED RATES FROM
3 L BIO-TREATMENT EXPERIMENT # 1



*Direct microscopic count

b) Test #2: 20°C, 20% solids

The experimental results of Test #2 are presented in Figure 5. The results can be summarized as follows:

- Bacterial populations remained constant throughout the first 43 hours and then slowly decreased.
- By hour 73 bacterial activity was slow, with protozoa present.
- At hour 112, there were no bacteria evident. The reactor was contaminated with protozoa which were believed to have consumed the bacterial population.
- pH levels remained in the range 6.6 - 7.2.

The protozoa present in the reactor were 10-20 um long, ovoid, with two unequal flagella. The tentative indentification for this organism was Cyathomonas sp.

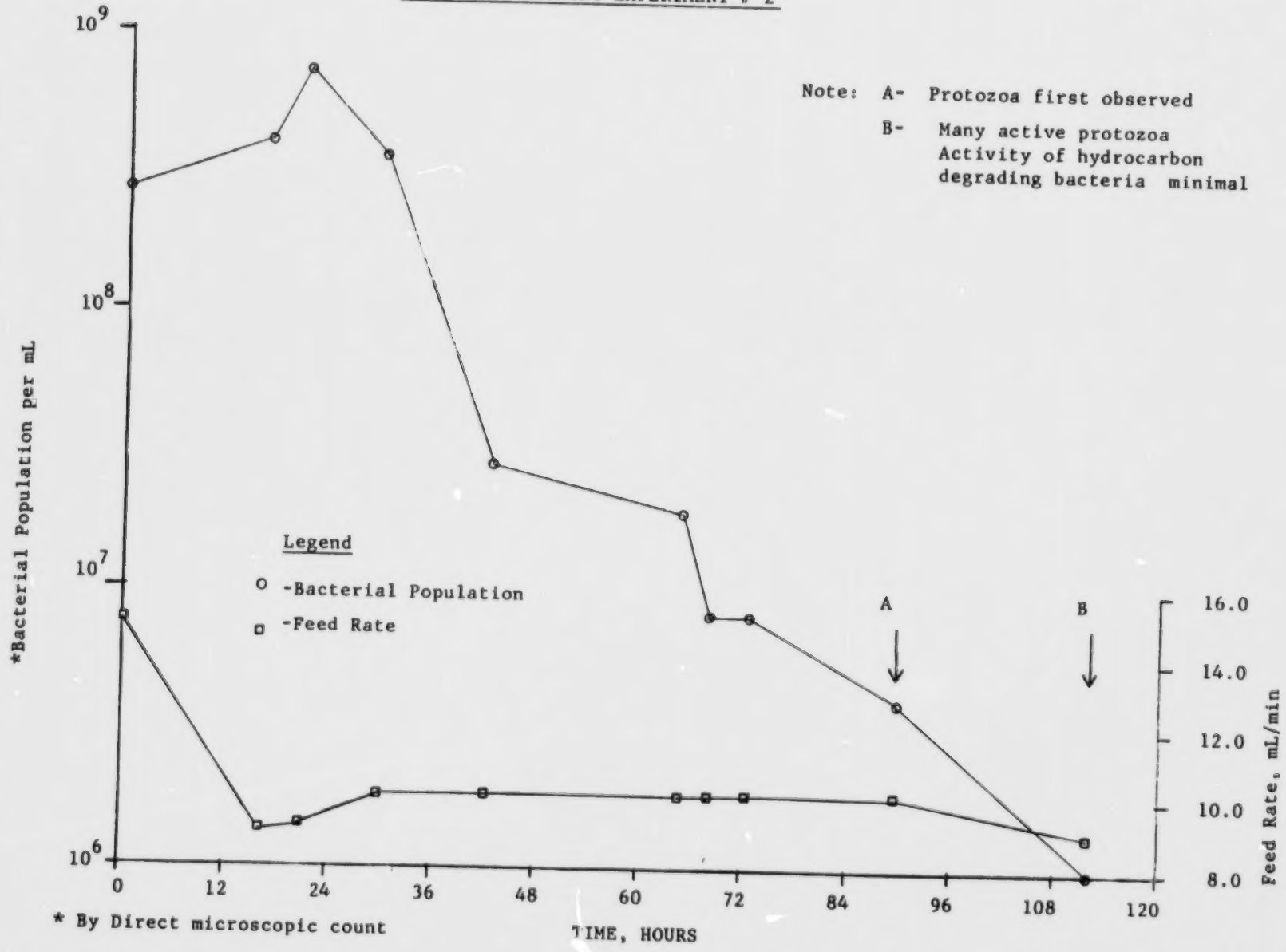
c) Test #3: 30°C, 25% solids

This test was conducted at 30°C to determine if increased temperature would result in decreased treatment time. The experimental results are presented in Figure 6. The results can be summarized as follows:

- Pump rate was increased 30% to account for the increased bacterial growth rate due to increased temperature.
- Bacterial activity began decreasing at hour 44.
- At hour 66, bacterial activity was slow, with the reactor contaminated with protozoa, as in Test #2.
- pH levels remained in the range 6.9 - 7.3.

Figure 5

BACTERIAL POPULATIONS AND FEED RATES FROM
3 L BIO-TREATMENT EXPERIMENT # 2

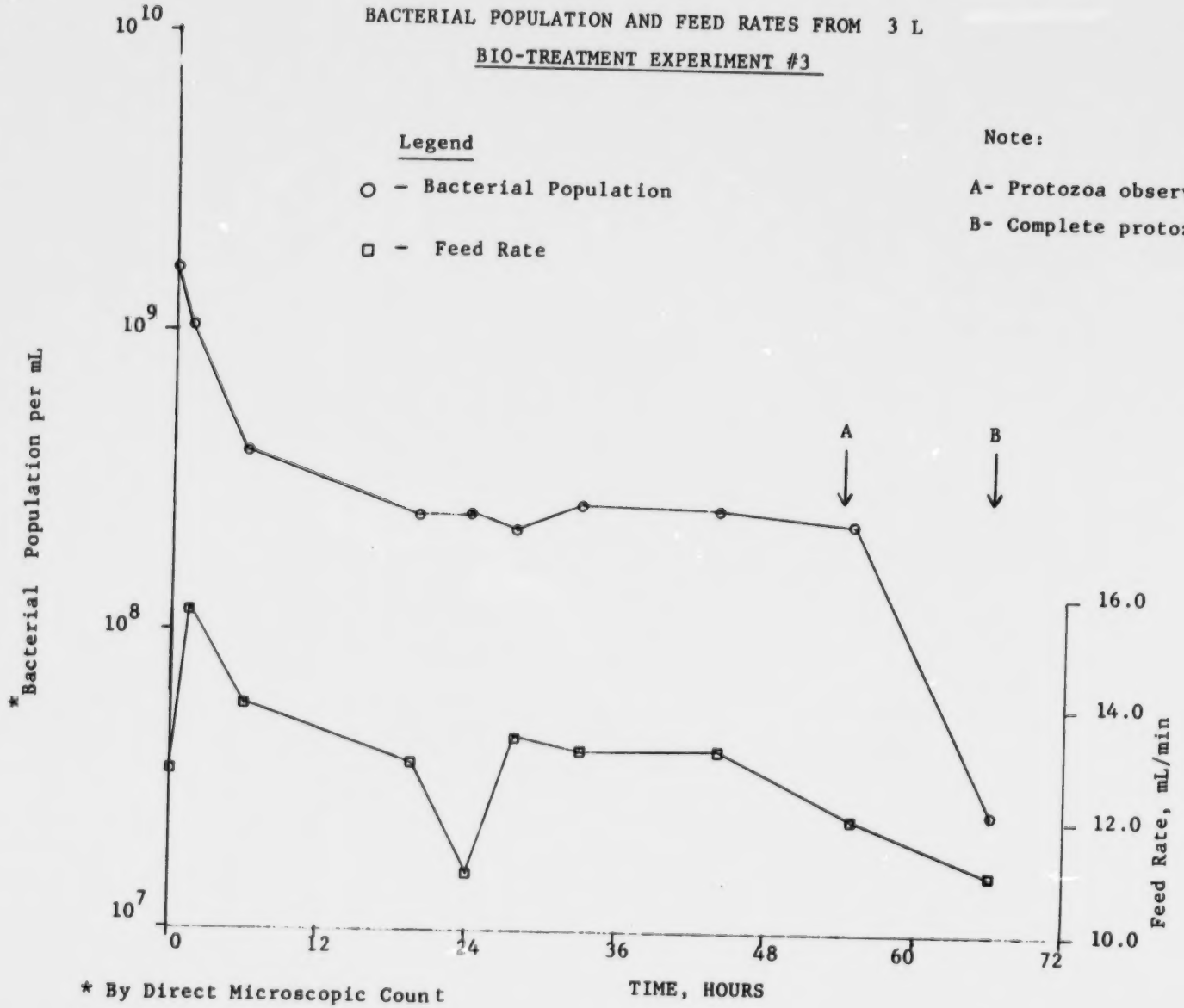


The experimental results of the 3 L reactor test can be summarized as follows:

- Bacterial populations remained relatively constant throughout the treatments. The end of the tests were marked by a decrease in the bacterial population.
- Protozoal contamination was believed to be a factor in the reduction in bacterial population.
- The reactor overflow solids contained only a small weight fraction of the total reactor contents (maximum 7.8%).
- Carbon assays from the reactor overflows were significantly higher than the feed material. This effect was more pronounced in the bacterial treatment than in the aqueous control. This effect was probably due to the action of a bacterial surface active agent.
- Only a small fraction of benzene soluble hydrocarbon was able to be removed from the feed material due to bacterial treatment (maximum 3.9%). This, however, was significantly better than the aqueous control, where only 0.32% was removed.
- Molybdenum assays were only slightly lower in the overflow solids. Selective carbon removal using decantation would not be possible with the amount of molybdenum carried over.
- The source of the protozoal contamination was not determined. Protozoa could be prevented in future tests by running the tests at high pH values (8.0 to 8.5) or by using an anti-protozoal agent.

Figure 6

BACTERIAL POPULATION AND FEED RATES FROM 3 L
BIO-TREATMENT EXPERIMENT #3



* By Direct Microscopic Count

In summary, the continuous tests removed only a small percentage of benzene soluble hydrocarbon from the total reactor solids. The amount of hydrocarbon removed by bacterial treatment however, was greater than the uninoculated aqueous control. The data infer that the bacterial treatment affected only the hydrocarbons present on the surface of the minerals. The organic extraction method stripped hydrocarbon thoroughly from the minerals on the surface and the interior of porous minerals, and hence may not be a good indication of surface hydrocarbon oxidation.

5.2.2 Pilot Scale Reactor Test (16 L)

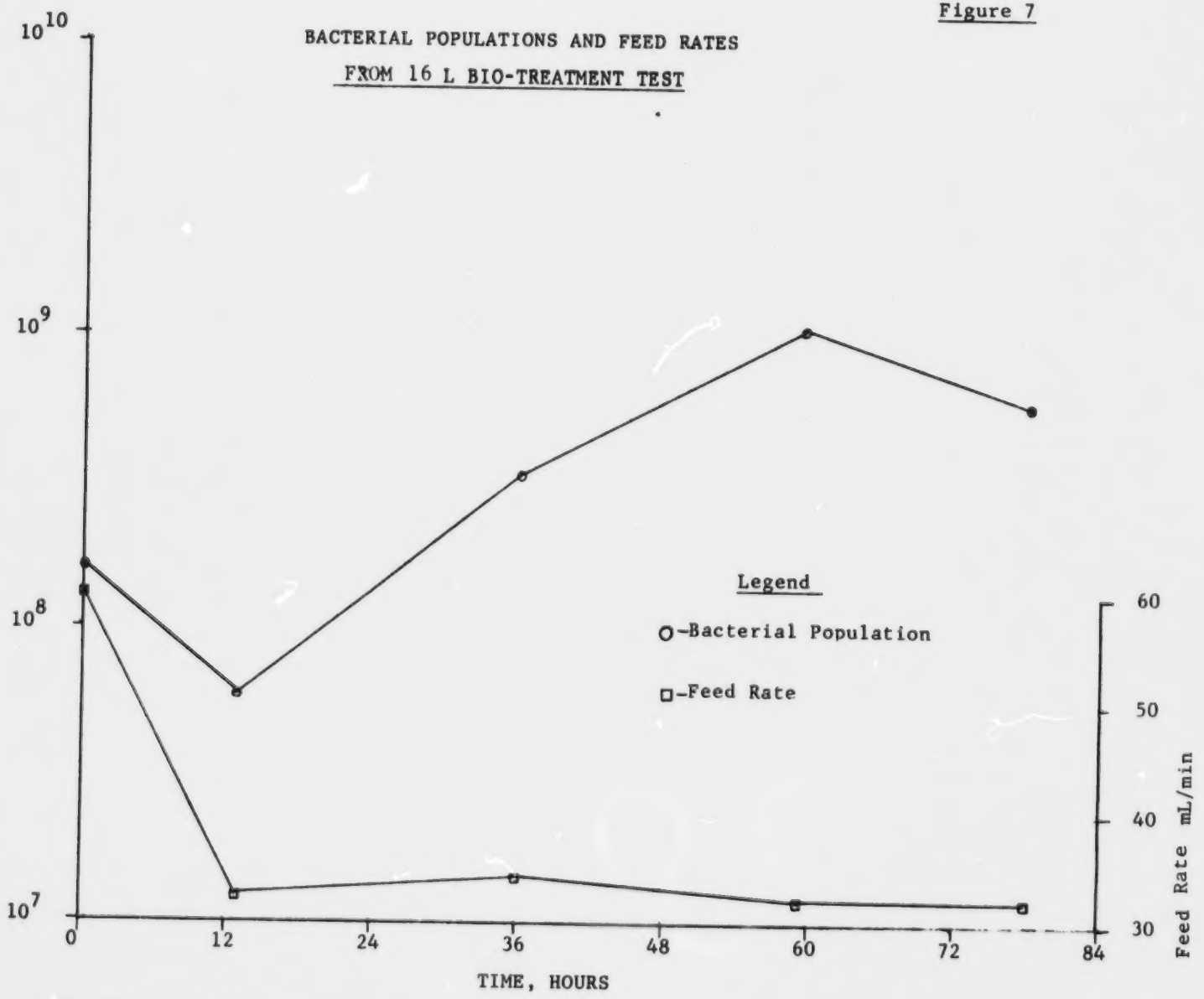
A 16 L air-lift reactor was used to treat 5 kilograms of molybdenum concentrate in a batch continuous-decantation mode. A surfactant was added to the nutrient solution to aid in the emulsification of hydrocarbon. Cycloning tests were performed subsequently to evaluate hydrocarbon-molybdenite separation efficiencies of treated versus untreated materials. The bacterial growth response of the 16 L test is presented in Figure 7. Data summarizing the experimental results are presented in Table 8.

The results of the test can be summarized as follows:

- The duration of the experiment was 78 hours, at which time 170 L of nutrient solution passed through the reactor.
- Bacterial activity remained active throughout the treatment process.
- The addition of surfactant caused a larger amount of solids to be carried through the overflow of the reactor (24.4%) compared to the 3 L tests.

Figure 7

BACTERIAL POPULATIONS AND FEED RATES
FROM 16 L BIO-TREATMENT TEST



* By Direct Microscopic count

Table 8

SUMMARY DATA FROM CONTINUOUS 16 L REACTOR TEST

Total Feed Volume : 187 L
Duration : 80 Hours
Temperature : 20°C
Pulp Density : 20% Solids

	Weight of Solids		Assay %			Distribution %		
	grams	Dist.%	C_{TOT}	C_{ORG}	Mo	C_{TOT}	C_{ORG}	Mo
Decant Overflow	1127	24.32	20.5	2.30	17.3	27.34	25.54	29.16
Reactor Contents	3508	75.68	17.5	2.15	13.5	72.66	74.46	70.84
Total	4635	100.00	(18.23)	2.19	(14.42)	100.00	100.00	100.00

Organic Carbon Displaced from Feed = (2.19-2.15)/2.19 = 1.83%

1044A

- The overflow did not preferentially remove carbon from the reactor. The addition of surfactant suspended both molybdenite and hydrocarbon particles, removing both from the reactor (see Table 8).
- The bacterial treatment removed 1.83% benzene soluble hydrocarbon from the reactor contents. Since the addition of surfactant did not effectively remove carbon, it is recommended that surfactant not be used as an addition to the nutrient solution.

In summary, there were no scale-up problems encountered with the 16 L bio-reactor system. It is anticipated that no problems would be encountered if larger reactor systems are employed.

5.3 Hydrocarbon Separation

5.3.1 Hydraulic Elution

The results from the hydraulic elution tests of bacterially treated and untreated molybdenum concentrates are presented in Table 9.

Only a small weight percentage of solids (0.36%) was decanted from the control test. The bacterial treatment enabled a minor increase in total weight decanted (0.81%).

The carbon grade in the overflow fraction was significantly higher than the feed material in both the treated and untreated samples.

Table 9

HYDRAULIC ELUTION TEST DATA

A) Bacterially Treated Concentrate

	Weight of Solids		Assay, %		Distribution	
	grams	Dist.%	C_{TOT}	Mo	C_{TOT}	Mo
Decant 1	2.35	0.62	23.5	11.30	0.755	0.608
Decant 2	0.35	0.09	40.3	6.00	0.193	0.048
Residue	377.30	99.29	19.2	11.51	99.052	99.344
Total	380.00	100.00	(19.25)	(11.50)	100.00	100.00

Total wt % C removed (0.755 + 0.193) = 0.948%

Total wt % Mo removed (0.608 + 0.048) = 0.656%

B) Untreated Concentrate

	Weight of Solids		Assay, %		Distribution	
	grams	Dist.%	C_{TOT}	Mo	C_{TOT}	Mo
Decant 1	0.79	0.23	37.5	6.71	0.472	0.131
Decant 2	0.46	0.13	43.0	4.00	0.315	0.044
Residue	346.00	99.64	18.0	11.69	99.213	99.825
Total	347.25	100.00	(18.08)	(11.67)	100.00	100.00

Total wt % C removed (0.472 + 0.315) = 0.787%

Total wt % Mo removed (0.131 + 0.044) = 0.175%

1044A

Molybdenum grades were lower in the overflow fraction than the feed material in both the treated and untreated samples. The bacterial treatment did not enable a cleaner separation of carbon from molybdenum.

The presence of molybdenum in both overflows may be caused by molybdenum slimes (10 um) which were carried into the overflow. The bacterial treatment may have enhanced elution of slimes due to surfactant action. Mineralogical analysis of concentrates confirms the presence of slimes.

5.3.2 Heavy Liquid Separation

Heavy liquid separation tests were performed to determine if bacterial treatment would improve hydrocarbon-molybdenite separation efficiencies using Na_2SO_4 solutions (S.G. 1.23) to separate the minerals based on their specific gravities. Separation tests were performed on the following materials:

1. Untreated molybdenum concentrate.
2. Uninoculated control decant material.
3. Treated concentrate from 3 L reactor Test #2.
4. Treated concentrate from 3 L reactor Test #3.

The results from the testwork are presented in Table 10. The results can be summarized as follows:

- The separation of carbon from molybdenum in all tests gave a clean float product, with high carbon grades (69.5% C) and low molybdenum content (0.25% Mo).
- Untreated material floated 18.8% weight of carbon.
- Bacterial treatment gave slightly better results, with 22.7% and 24.0% weight carbon removed from Tests 2 and 3, respectively.
- The control experiment (uninoculated) did not affect carbon removal efficiencies.

In summary, heavy liquid separation using Na_2SO_4 did not effectively separate hydrocarbon from molybdenite. The bacterial treatment, however, gave slightly better results over the untreated controls. This increase may be caused by the partial removal of "sticky" benzene soluble hydrocarbons (see Section 5.3.1). A more intense bacterial treatment may further improve carbon separation by removing these undesirable hydrocarbons. There may also be more effective hydrocarbon removal with higher S.G. heavy liquids (i.e. 1.3 grams/cc).

5.3.3 Flotation

Data summarizing the flotation tests is presented in Table 11.

Orzan "A"

Orzan "A" was used to float hydrocarbon while depressing molybdenite. Two reagent concentrations were tested, 3.0 kg/t and 6.0 kg/t.

Table 10

HEAVY LIQUID SEPARATION DATA

	Solids Weight		Assay, %		Distribution, %	
	grams	Dist., %	C_{TOT}	Mo	C_{TOT}	Mo
Continuous Treatment #2						
Float	0.72	5.46	72.50	0.86	22.71	0.25
Sink	12.47	94.54	14.25	19.30	77.29	99.75
Total	13.19	100.00	(17.43)	(18.29)	100.00	100.00
Continuous Treatment #3						
Float	0.69	5.28	75.00	0.76	24.00	0.21
Sink	12.37	94.72	13.25	19.00	76.00	99.79
Total	13.06	100.00	(16.51)	(18.03)	100.00	100.00
Untreated Concentrate						
Float	0.59	4.76	75.00	0.55	18.76	0.13
Sink	11.80	95.24	16.25	19.10	81.24	99.87
Total	12.39	100.00	(19.05)	(18.22)	100.00	100.00
Aqueous Control						
Float	0.54	4.53	69.50	0.61	17.29	0.14
Sink	11.39	95.47	15.75	18.50	82.71	99.86
Total	11.93	100.00	(18.18)	(17.67)	100.00	100.00

1044A

Table 11

FLOTATION TEST SUMMARY

Organ "A" Flotation @ 3.0 kg/t

	Assay, %		Distribution, %		
	C_{TOT}	Mo	Wt.	C_{TOT}	Mo
Untreated Concentrate					
Float	19.2	15.7	15.69	20.07	11.86
Tail	12.0	18.3	84.31	79.93	88.14
Total	(12.98)	(17.95)	100.00	100.00	100.00
Treated Concentrate					
Float	13.68	14.56	21.40	19.37	16.68
Tail	15.50	19.00	78.60	80.63	83.32
Total	(15.11)	(18.05)	100.00	100.00	100.00

Organ "A" Flotation @ 6.0 kg/t

	Assay, %		Distribution, %		
	C_{TOT}	Mo	Wt.	C_{TOT}	Mo
Untreated Concentrate					
Float	20.5	13.9	18.49	20.09	17.66
Tail	18.5	14.7	81.51	79.91	82.34
Total	(18.87)	(14.55)	100.00	100.00	100.00
Treated Concentrate					
Float	14.42	15.33	20.94	19.27	14.52
Tail	16.00	23.90	79.06	80.73	85.48
Total	(15.67)	(22.10)	100.00	100.00	100.00

1044A

Table 11 cont.

Aero 633 Flotation @ 0.2 kg/t

	Assay, %		Distribution, %		
	C_{TOT}	Mo	Wt.	C_{TOT}	Mo
Untreated Concentrate					
Float	7.0	14.1	29.53	10.97	21.96
Tail	23.8	21.8	70.47	89.03	78.04
Total	(18.84)	(18.96)	100.00	100.00	100.00
Treated Concentrate					
Float	14.5	15.2	25.28	20.96	21.84
Tail	18.5	18.4	74.72	79.04	78.16
Total	(17.49)	(17.59)	100.00	100.00	100.00

Aero 633 Flotation @ 0.2 kg/t plus 0.01% $PSMO_{20}$

	Assay, %		Distribution, %		
	C_{TOT}	Mo	Wt.	C_{TOT}	Mo
Untreated Concentrate					
Float	16.5	23.0	13.58	19.80	20.52
Tail	10.5	14.0	86.42	80.20	79.48
Total	(11.31)	(15.22)	100.00	100.00	100.00
Treated Concentrate					
Float	20.0	20.4	27.45	43.04	35.34
Tail	10.0	14.1	72.55	59.96	64.66
Total	(17.50)	(15.84)	100.00	100.00	100.00

1044A

The bacterial treatment was not successful in significantly removing carbon by flotation at the 3.0 kg/t dosage. The bacterial treatment at the 6.0 kg/t dosage only slightly improved the floation response.

The Orzan "A" flotation testwork did not remove significant carbon from either bacterially treated or untreated material. Consequently, further testwork using this reagent was discontinued.

Aero 633

Cyanamid Aero 633 depressant was used to depress hydrocarbon minerals while floating molybdenite. The bacterial treatment did not improve the flotation of molybdenite or the depression of hydrocarbon.

Alkaril $PSMO_{20}$ surfactant was used to aid in the dispersion of hydrocarbon. The surfactant did not improve flotation response.

In summary, further flotation testwork was dicontinued, due to poor selectivity in flotation response. The ultra-fine nature of the molybdenite, observed in the mineralogical analysis of the concentrate, may account for the difficulties experienced in an effective selective separation. Desliming of the concentrate prior to testwork may improve future flotation tests.

Detailed mass balance data from the flotation tests are presented in Apprendix IV.

5.3.4 Cycloning Testwork

Data summarizing the cycloning tests of bacterially treated and untreated molybdenum concentrate is presented in Table 12.

The cycloning testwork can be summarized as follows:

- The bacterial treatment showed improvement in hydrocarbon rejection over the untreated concentrate, both in terms of grade improvement and weight rejected.
- Molybdenite losses to the overflow were high, with approximately 40% weight of molybdenum being lost.

Bacterial surfactant action, coupled with partial benzene soluble hydrocarbon removal are suggested as possible mechanisms for the improvements effected by bacterially treated material.

High molybdenite losses may be caused by the presence of ultra-fine molybdenum slimes, contributing to the poor cycloning responses.

Slimes removal prior to cycloning should be pursued in future testwork to give a better indication of the effectiveness of bacterial treatment.

Table 12

CYCLONING TEST SUMMARY

	Assay, %		Distribution, %		
	C_{TOT}	Mo	Wt.	C_{TOT}	Mo
Untreated Concentrate					
30 PSI O/F	24.66	16.0	38.02	62.47	33.36
U/F	9.09	19.6	61.98	37.53	66.64
Total	(15.01)	(18.23)	100.00	100.00	100.00
40 PSI O/F	24.61	16.2	38.87	69.28	34.34
U/F	6.94	19.7	61.13	30.72	65.66
Total	(13.81)	(18.34)	100.00	100.00	100.00
Treated Concentrate					
30 PSI O/F	27.49	15.8	43.71	73.51	40.68
U/F	7.69	17.9	56.29	26.49	59.32
Total	(16.35)	(16.98)	100.00	100.00	100.00
40 PSI O/F	25.27	15.8	42.03	74.45	39.15
U/F	6.29	17.8	57.97	25.55	60.85
Total	(14.27)	(16.96)	100.00	100.00	100.00

1044A

5.4 Mineralogical Examinations

5.4.1 Wet Mounts

The microscopic examination of wet mount preparations of treated and untreated molybdenum concentrate revealed noticeable alterations in the particle associations.

Figure 8 is a photomicrograph of a 5% slurry of untreated concentrate. The agglomeration of the particles was clearly evident. Similarly, Figure 9 shows a photomicrograph of the slurry from the uninoculated control experiment. The same particle agglomeration was noted.

The bacterially treated concentrate, illustraed in Figure 10, showed the majority of particles as distinct and unagglomerated. The bacterial treatment has clearly affected the nature of particle association. The effect that the bacterial treatment had on the material, however, can only be speculated. The unclotting may have been due to the action of a bacterially produced surfactant or by the removal and/or oxidation of the "sticky" hydrocarbons from the mineral surfaces.

5.4.2 Polished Thin Sections

Figure 11 gives a general overview of minerals from the untreated concentrate. Molybdenite, chalcopyrite and carbonaceous gangue are clearly evident. Figure 12 shows a carbon particle rimmed by ultra-fine molybdenite. This mineral association may be due to the action of the "sticky" benzene soluble hydrocarbons.

Figure 13 illustrates a hydrocarbon particle in the bacterially treated concentrate. The rimming of hydrocarbon with molybdenite was not observed in the treated concentrate.

Figure 14 is a photomicrograph of the reactor overflow solids. Note the presence of minute ore particles. The fine nature of the minerals in the overflow indicates that selective elutriation would not be an effective separation method.

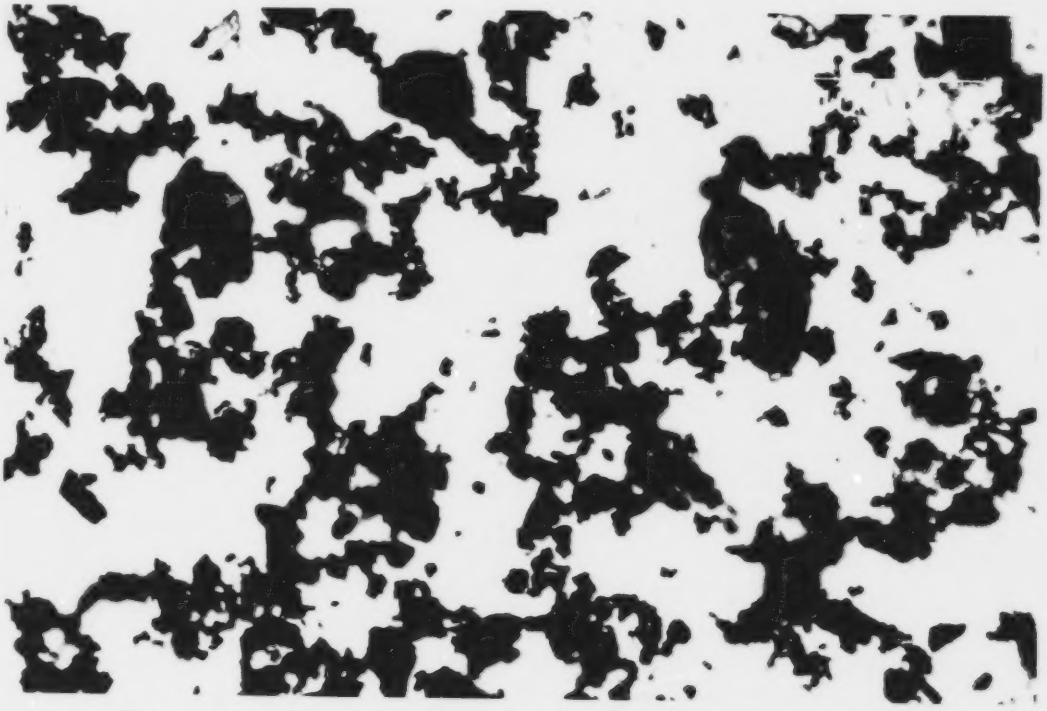


Figure 8 - Photomicrograph of Untreated Concentrate
Wet Mount. Transmitted Light, 200X
Note: The agglomeration of the material.
Very few free particles evident.

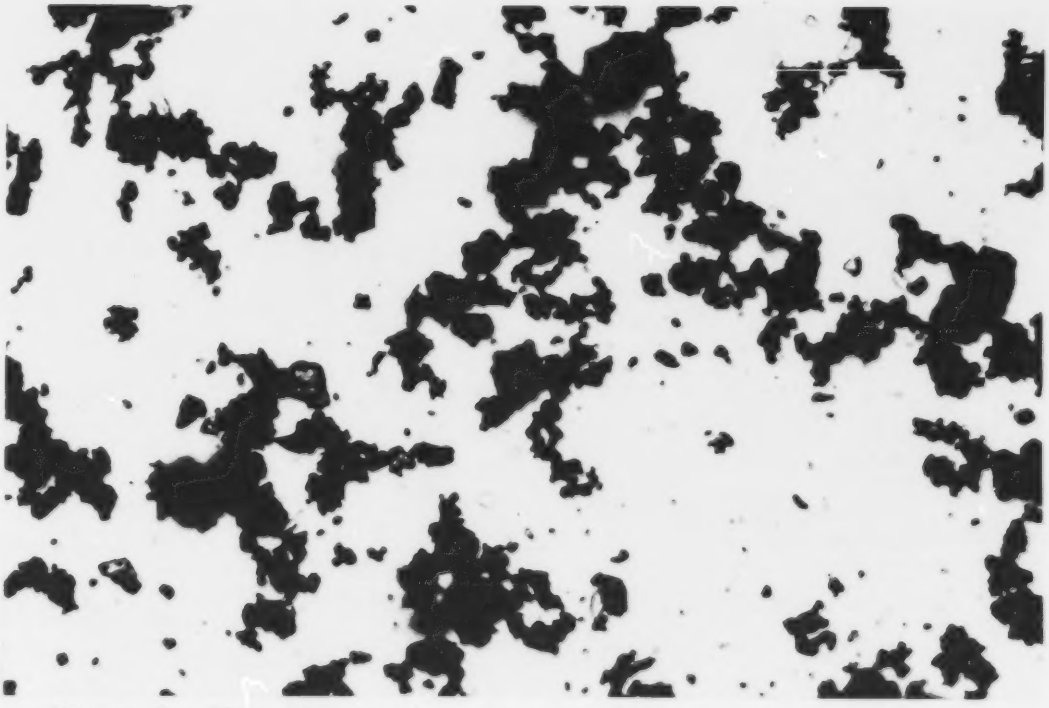


Figure 9 - Photomicrograph of Uninoculated Control Concentrate
Wet Mount. Transmitted Light, 200X
Note: Concentrate is still agglomerated.

1044A

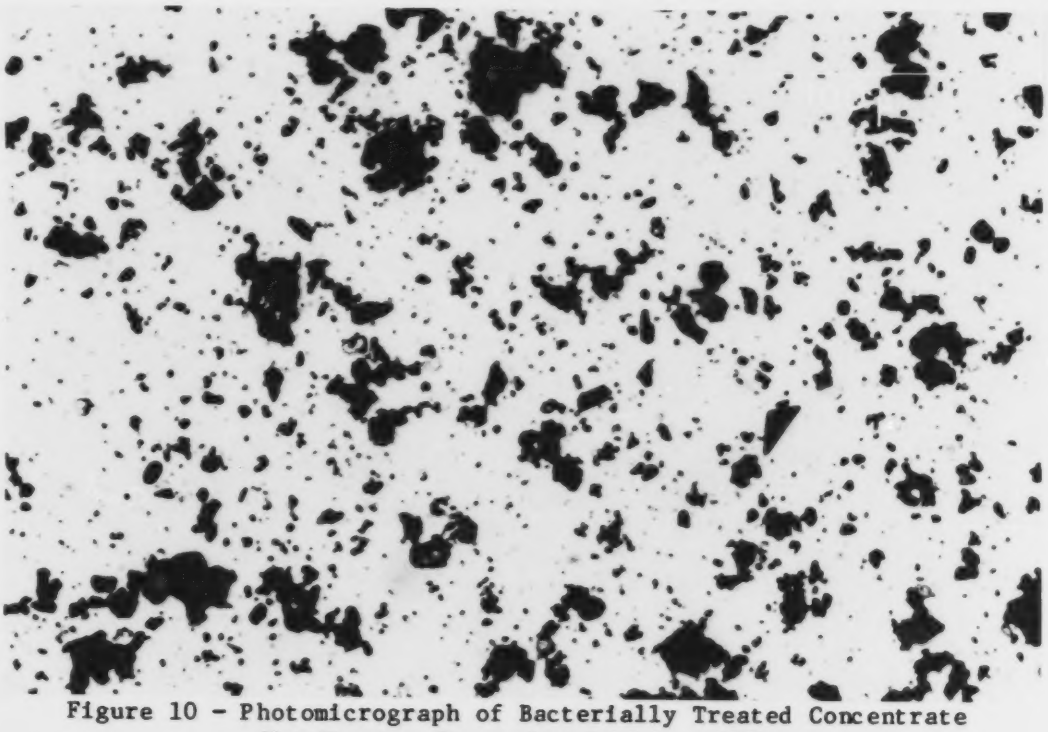


Figure 10 - Photomicrograph of Bacterially Treated Concentrate
Wet Mount. Transmitted Light, 200X
Note: The majority of the concentrate particles
are unattached (free).

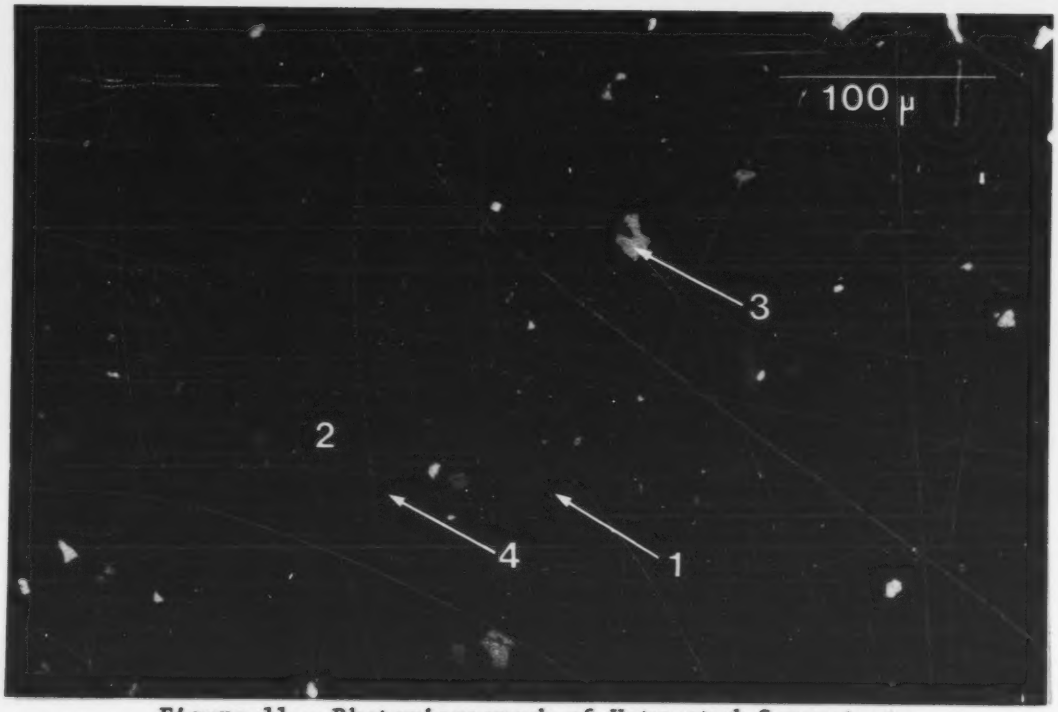


Figure 11 - Photomicrograph of Untreated Concentrate
Polished Section. Reflected Light, 200X.
Note: The occurrence and size of molybdenite (1)
hydrocarbon (2) and chalcopyrite particles (3).
Also note the presence of very fine molybdenite slimes (4).

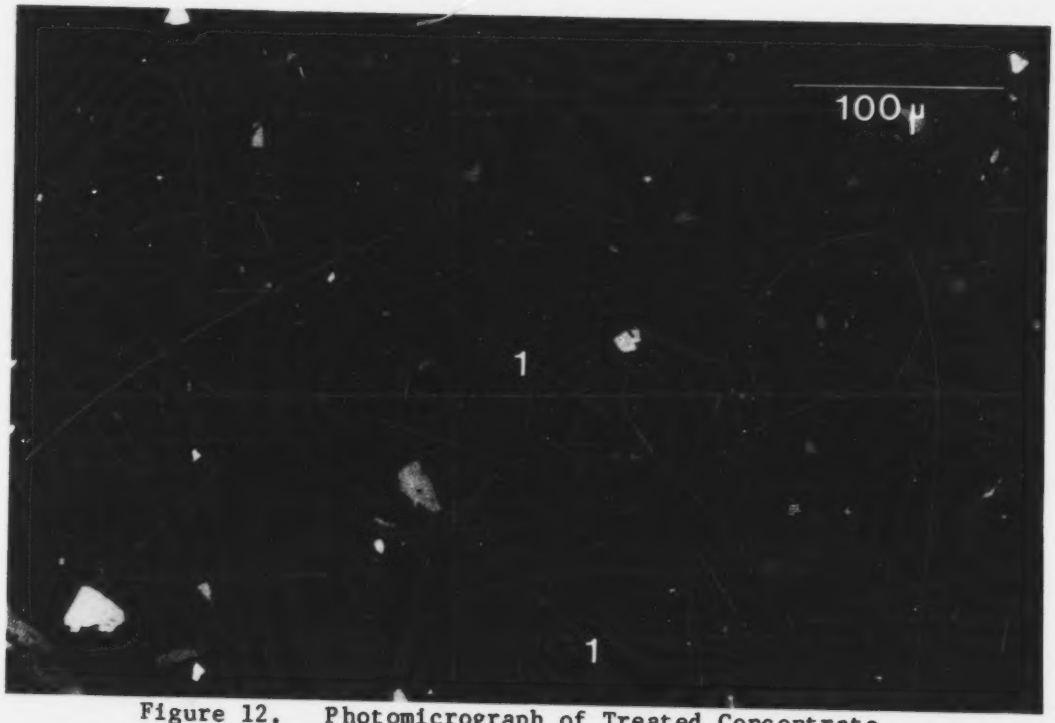


Figure 12. Photomicrograph of Treated Concentrate Polished Section. Reflected Light, 200X
Note: Carbon particles (1) are no longer rimmed with grey molybdenite slimes.

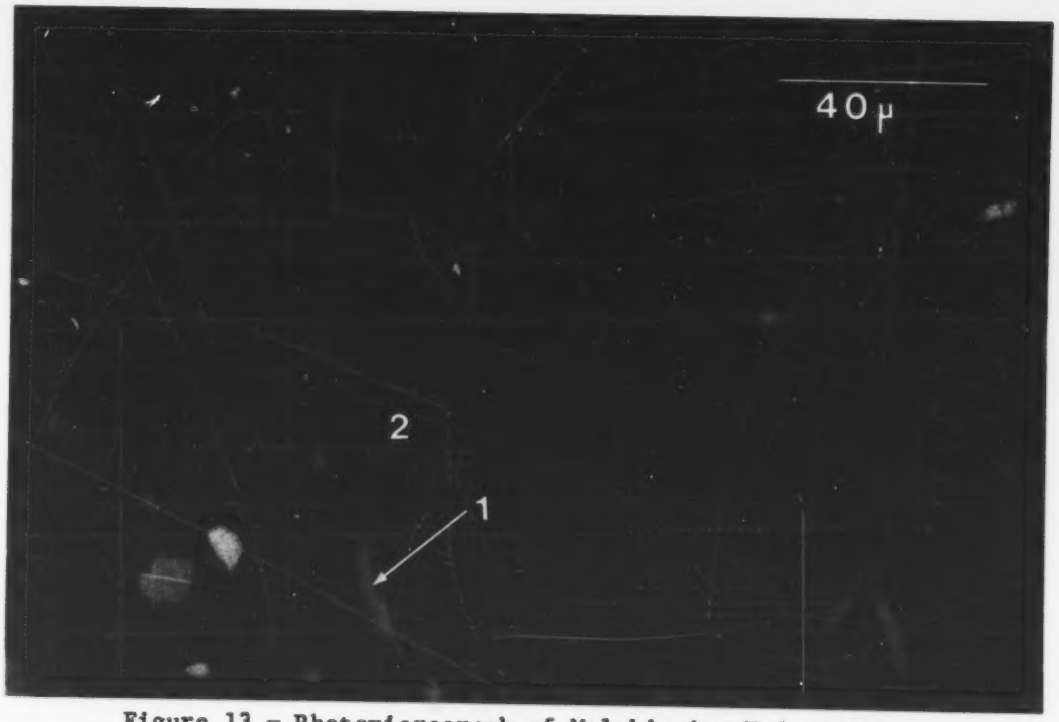


Figure 13 - Photomicrograph of Molybdenite-Hydrocarbon Associations in Untreated Concentrate - Polished Section. Reflected Light, 500X
Note: The presence of ultra fine molybdenite particles (1) rimming the hydrocarbon particle (2).

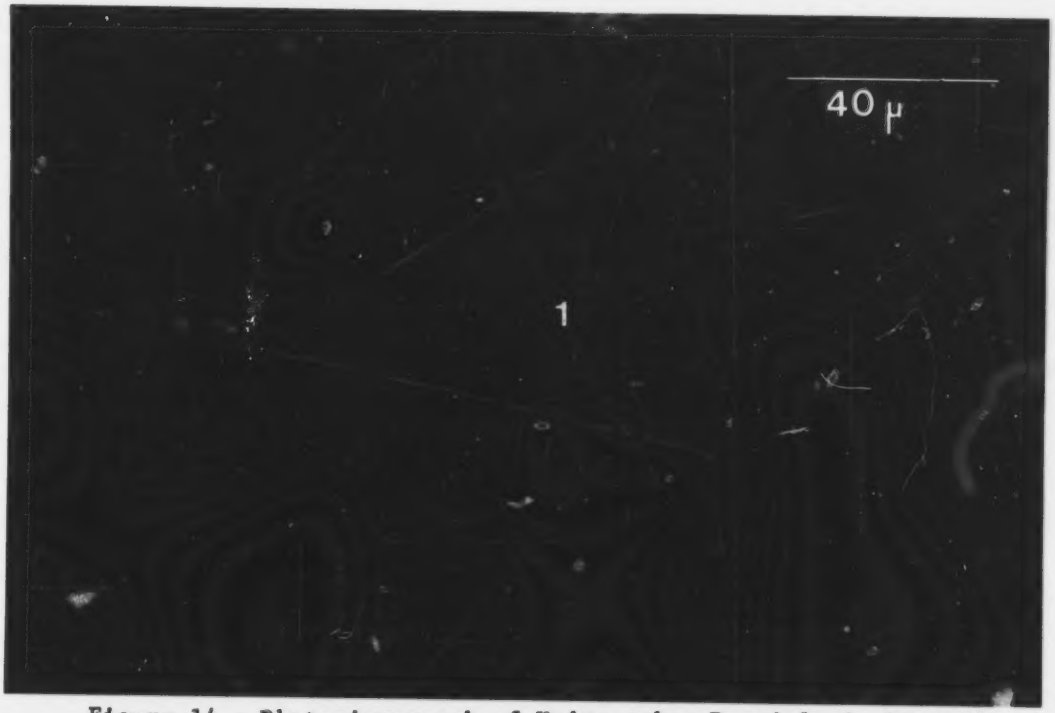


Figure 14 - Photomicrograph of Hydrocarbon Particle in Treated Concentrate - Polished Section. Reflected Light, 500X
Note: Hydrocarbon particle (1) is no longer rimmed with molybdenite slimes.

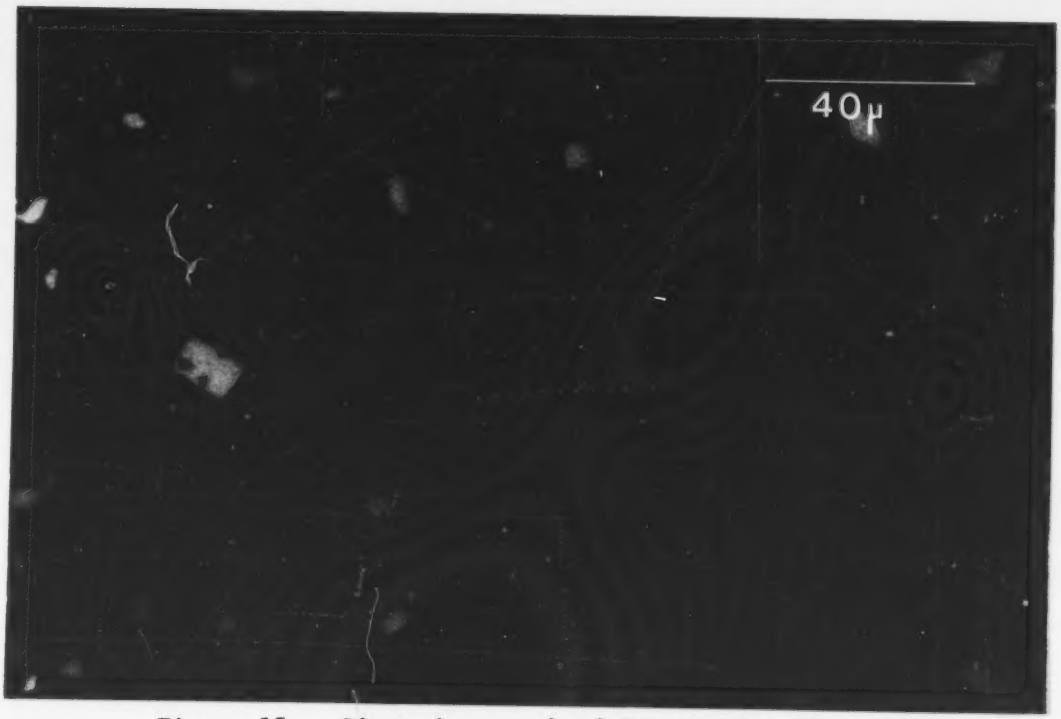


Figure 15 - Photomicrograph of Reactor Overflow Solids Polished Section. Refelected Light, 500X.
Note: The presence of fine particles of all mineral types.
1044A

6.0 ECONOMIC FEASIBILITY

The purpose of this section is to determine the operating cost for bio-treatment of a hydrocarbon contaminated molybdenum concentrate. This is being done prior to having selected the preferred method of separating hydrocarbon from molybdenite. It is assumed that all equipment is available and that no capital outlay is required for construction. All capital equipment except for the bioreactor is standard mineral processing equipment. The bioreactor design is of the air-lift type as illustrated in Figure 2.

6.1 Process Description

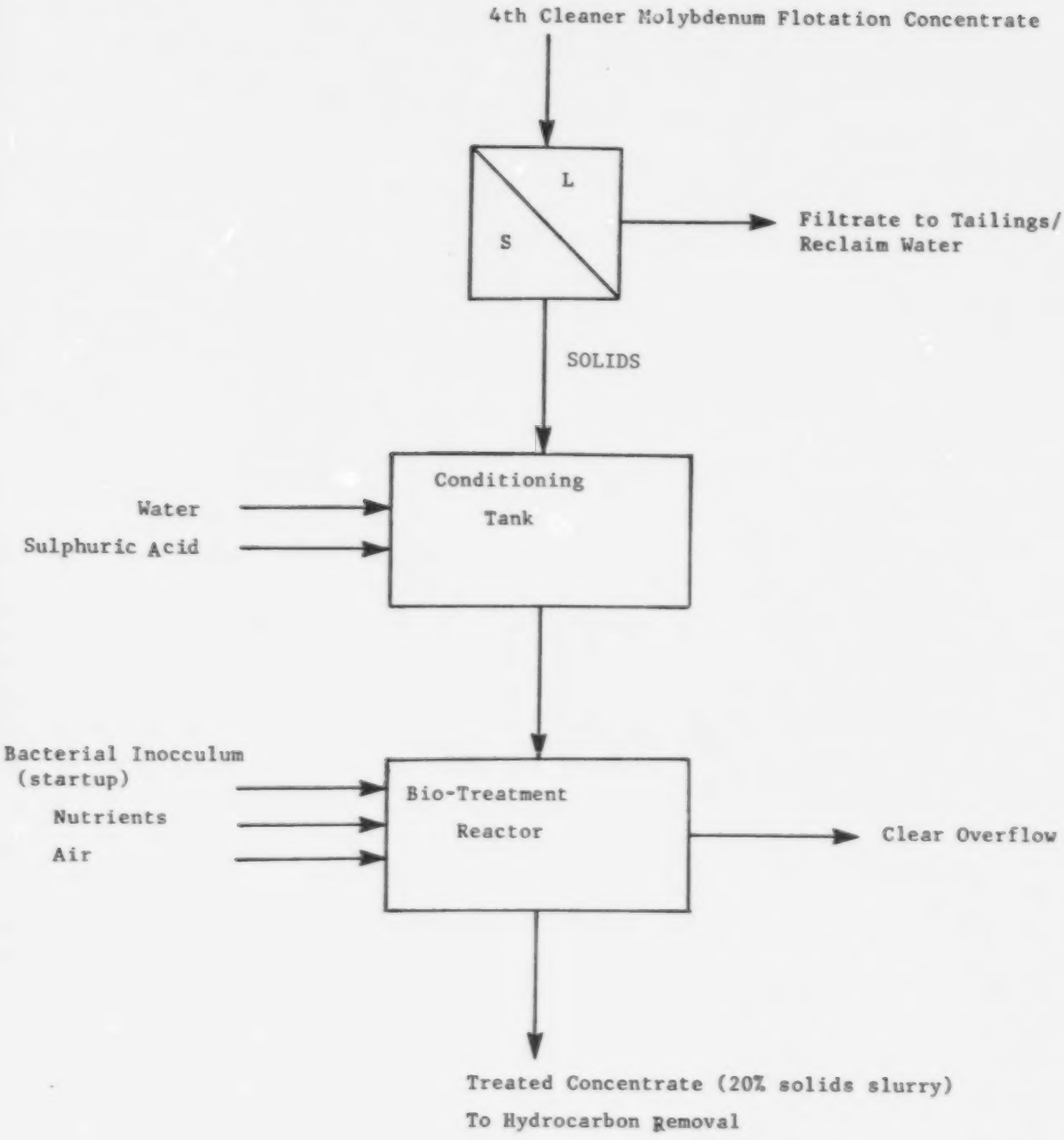
A flowsheet describing the bio-treatment process is outlined in Figure 16. The feed material for the circuit is flotation concentrate from the molybdenum circuit. For the biological treatment to be effective, a carbon content of 8-20% is required. Flotation concentrate from the 4th cleaner has been selected as bio-treatment feed, since previous hydrocarbon removal efforts were focused at this stage, and because carbon grades are in the required range.

Concentrate material from the 4th cleaner is filtered, with the filtrate recirculated to the flotation circuit. The filter cake is repulped to 20% solids in a conditioning tank. The pH of the pulp is adjusted to 7.0 with sulphuric acid. The conditioned slurry is then fed into the bioreactor.

The solids are to be treated in the bioreactor for a four day period. The bio-treatment can take place in either a batch or continuous treatment mode with respect to solids.

Figure 16

BIO-TREATMENT PLANT FLOWSHEET



For a batch treatment, solids are stockpiled for a four day period. The solids are then pulped to 20% solids, conditioned and fed to the bioreactor. Throughout the bio-treatment process, nutrient solution is fed to the reactor at 10% of the reactor volume per hour. Clear decant solution overflows at the same rate. After a four day treatment time, the slurry is either filtered and stockpiled, or sent directly to metallurgical separation. The advantage of the batch process is that only a single bioreactor is required. The disadvantage is solids inventory hold-up before treatment and possibly after treatment.

In a continuous process, filtered concentrate is continuously fed to the conditioning tank. The conditioned slurry is then fed to the bioreactor system. For a continuous system to be effective, a series of tanks is required to distribute the retention time and preventing solids short circuiting. For example, if a four day retention time is required, four tanks with a retention time of one day each could be used. To each of these tanks fresh nutrient solution is added at a rate corresponding to 10% of the reactor volume per hour. Clean overflow containing bacteria and reaction products are sent to tailings. Treated slurry from the last reactor stage can be sent directly to further metallurgical processing. The advantages of the continuous process are that no stockpiling is required and no process interruptions are experienced. The disadvantages are that capital costs would be higher than for a single tank system operating batchwise.

1044A

6.2 Operating Costs

Operating costs have been determined for a batch bio-treatment process with an 8 TPD capacity. Feed material is from the fourth cleaner section of the molybdenum flotation circuit. The operating cost estimate includes the following:

- Process reagents
- Power
- Direct operating labour
- Maintenance labour and supplies.

The estimate is based on:

- Calculated material and energy balances
- Reagent requirements determined from testwork.

Design Criteria for Biological Concentrate Treatment

Concentrate feed rate	-	8 tonnes/day
Bioreactor size	-	140,000 L (140 m^3)

- assuming a 4 day retention time at 20% solids
- reactor dimensions 9 m high, 4.45 m diameter.

Nutrient feed rate (10% solution turnover/hour)

= 14,000 L/hour

Operating Cost Estimate

1. Process Reagents

Reagent Type	Consumption kg/t	Unit Price $/tonne Reagent	Cost of Usage $/tonne Conc.
H_2SO_4	2.6	130	0.34
$(NH_4)_2SO_4$	4.2	400	1.68
Na_3PO_4	6.3	1262	7.95
Yeast Extract	2.1	$50/kg	105.00
Total Reagent Cost			114.97

2. Energy

Equipment	Power Requirement kW	Energy Price $/kWh	Energy Cost $/tonne Conc.
Air Compressor (aeration)	460	0.05	69.00
Pumps	25	0.05	3.75
Total Energy Costs			72.75

3. Labour Costs

Personnel Required/shift	Shifts/day	Wage $/hour	Labour Cost $/tonne Conc.
1	3	14.0	42

3. Maintenance Labour and Supplies

*Est. Capital Cost $	Est. Maintenance Cost % Capital Cost/Year	Maintenance Cost $/tonne Conc.
500,000	3.5	6.00

TOTAL ESTIMATED OPERATING COST $235.72/tonne Conc.

Estimated Value of the Cleaner Concentrate @ 20% MoS_2
$880.00/tonne

* Includes only process equipment, pumps and auxiliaries dedicated to the bio-treatment flowsheet.

Notes:

1. Reagents were costed at unit price per tonne except for yeast extract (cost/10 kg) from reagent and commodity suppliers.

2. The air compressor power requirement was based on a 90 kPa head (9 m water) with an aeration rate of 1.0 m^3 air/m^3 pulp/min. Energy load on the compressor was calculated at 1.64 kW/m^3 of water at 90 kPa absolute pressure. Slurry density was 1.2 grams/cm^3. Efficiency of the compressor was 60%.

3. Pump energy requirements were based on five 5 kW pumps for vacuum filtration of concentrate, reactor solution overflow transfer and slurry pumping.

1044A

4. Labour and maintenance costs were based on adjusted rates from the files of Witteck Development Inc.

5. The value of molybdenum sulphide concentrate was calculated using $2.0/lb for pure molybdenum sulphide.

6.3 Feasibility Assessment

Based on this operating cost estimate, a bio-treatment process would be a reasonable addition to the present metallurgical flowsheet. This conclusion is valid only if the bio-treatment process results in a saleable molybdenum concentrate.

The highest operating cost components were yeast extract ($105.00/tonne conc.) and power for reactor aeration ($69.00/tonne conc.).

Yeast extract, a vitamin and amino acid source for the microorganisms, may be replaced by less expensive industrial waste products. Possible alternate sources may be corn steep liquor from corn starch processors, or brewery products (i.e. spent yeast). It is not possible to estimate the purchase price for these alternatives as an assured supply must be negotiated on a contract basis.

The cost of aeration is directly proportional to the reactor head pressure. For the reactor under question, a height:diameter ratio of 2 was used. If, for example a height:diameter ratio of 0.5 was used, the compressor energy load would be 230 kW or $34.50/tonne concentrate compared to $69.00/tonne concentrate for the quoted reactor.

This cost analysis and flowsheet design are intended to convey the relative merits of a batch biotreatment process. A more detailed study would be required to justify any capital expenditure or plant modifications.

1044A

7.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions summarize the findings of this research:

1. An optimal media was determined for the growth of a mixed culture of hydrocarbon degrading microorganisms. The nutrient formula was:

   0.2 g/L $(NH_4)_2 SO_4$
   0.07 g/L KH_2PO_4
   0.07 g/L Yeast Extract

   The above formula resulted in a average bacterial doubling time of 71 minutes at 20°C and pH 7.0. Reducing the concentration of any component of the nutrient formula decreased the bacterial growth rate. Bacterial growth was not sensitive to pH in the range 6.0 to 8.0, or to temperatures in the range 18 to 30°C.

   An average bacterial doubling time of 308 minutes was noted for tests using mill process water. Toxic elements (CN^-, S^{2-}, Mo, Cu) in the process water adversely affected bacterial growth. Filtering the concentrate slurry and repulping the filter cake in fresh water reduced the total cyanide level by a factor of 8.8. Precipitation with $FeCl_3$ reduced the total cyanide content by 4.4.

2. Continuous decantation studies (batch solids) enabled bacterial treatment to proceed under optimal growth conditions for a two to three day period. During concentrate treatment, bacterial populations were in the order of 10^7 to 10^9 organisms/mL of solution.

Contamination with protozoa was consistently experienced after 55 to 90 hours of bio-treatment. The dominant protozoal contaminant was tentatively identified as Cyathomonas sp. This contamination may be controlled in future tests by operating at higher pH values (i.e. 8.0-8.5) or by using antiprotozoal agents.

The continuous bio-treatment of concentrate removed 1.83 to 3.89% of contained benzene soluble hydrocarbon. By comparison, the uninoculated control test removed 0.32% benzene soluble hydrocarbon. Solid losses to the reactor overflow ranged from 2.8 to 7.8 wt.%. The molybdenum content of the overflow ranged from 15.0 to 16.8% Mo. When surfactant was used to aid in particle dispersion, the overflow weight loss was 24.2%.

The focus in future testwork should be to limit protozoal growth and thus allow increased reaction time for bio-oxidation of the hydrocarbon. This may result in a much greater removal of benzene soluble hydrocarbon from the surface of the concentrate particles and consequently improved metallurgical response.

3. Metallurgical Separation

a) Hydraulic Elution

Hydraulic elution was ineffective in separating hydrocarbon and molybdenite particles from bio-treatment residue. The hydrocarbon/molybdenite separation efficiences were not improved by bio-treatment compared to control samples. Bio-treatment resulted in a higher carry-over and loss of molybdenite to elution overflow. A bacterially produced surfactant may have aided in the dispersion of fine molybdenum particles during elution and consequently greater losses.

b) Flotation

No improvements in flotation response were experienced when comparing separation efficiencies of bacterially treated versus untreated materials. No significant selectivity was experienced with the reagents tested.

c) Heavy Liquid Separation

Heavy liquid separation yielded a pure hydrocarbon float product (>69.5% C) with little molybdenum content (<0.25% Mo). Bacterial treatment improved carbon removal from 18.8 wt% C (untreated) to 24.0 wt % C (treated).

This separation method provided the lowest molybdenum losses of any of the methods tested. It is anticipated that a more thoroughly bio-treated concentrate would result in even further carbon removal.

It is recommended that future test programs include heavy liquid separation tests of intensely bio-treated concentrates. The use of heavy liquids (inorganic) with specific gravities greater than 1.23 g/cm^3 should be investigated.

d) Cycloning

Cycloning was the most effective method tested for removing residual carbon from the concentrate. However, molybdenum losses to the overflow were high. Bacterial treatment improved carbon rejection from 69.3 wt% C (untreated) to 74.5 wt% C (treated).

Future metallurgical testwork should be geared toward optimizing cycloning or heavy liquid separation responses. A combination of cycloning in heavy liquid may prove to be an effective carbon removal method.

4. Microscopic examination of wet mount preparations noted that untreated concentrate particles agglomerated with very few free particles evident. Examination of the bacterially treated concentrate showed distinct and separate concentrate particles. This difference in particle dispersion is believed to be caused by the action of a bacterially produced surfactant and/or by hydrocarbon surface oxidation.

   Examination of polished thin sections of untreated concentrates showed the existence of fine molybdenum slimes (<10 um) rimming hydrocarbon particles. Bacterially treated concentrate showed the existence of slimes although the rimming phenomenon was not evident. Reactor overflow product contained mostly mineral slimes.

   It is suspected that the extreme fine particle size of the concentrate adversely affected hydrocarbon-molybdenite separation, irrespective of bacterial treatment. It is recommended that a detailed size analysis of the concentrate be conducted prior to any future testwork.

5. The estimated operating costs for a four day batch bio-treatment process was $235.00/tonne. The highest cost components were yeast extract (a vitamin and amino acid source) and compressed air for reactor aeration. The estimated value of molybdenum concentrate at the fourth cleaner was $880.00/tonne at 20% molybdenum sulphide.

   Operating costs can be significantly reduced by finding an alternative and less expensive source of yeast extract. There is also some latitude for optimizing power consumption for compressed air through decreased aeration rates and/or reactor design improvements.

1044A

In summary, bacterial treatment was successful in separating agglomerated mineral species from a hydrocarbon contaminated concentrate. The bacterial treatment marginally improved the effectiveness of mineral separation, when cycloning or heavy liquid separation was used. Metallurgical separations on the whole were not effective, and this is attributed at least partially to the presence of molybdenite slimes. The use of bacterial treatment for the dispersion of agglomerated ore particles may be a valuable treatment where conventional dispersants and surfactants are ineffective. The use of "tailor-made" microbial surfactants may hold promise as a future technology.

It is recommended that work be undertaken in the following areas to optimize the bacterial treatment process:

- Detailed size analysis of the molybdenum concentrate, indicating size distributions of carbon and molybdenum.
- Prevention of protozoal contamination.
- Extension of bio-treatment times to determine maximum possible hydrocarbon removal.
- Cycloning of bio-treated deslimed concentrate in heavy liquid.
- Isolation and characterization of microbial surfactants.

8.0 ACKNOWLEDGMENTS

Witteck Development Inc. gratefully acknowledges the receipt of concentrate samples, reclaim water, amd considerable support from Utah International. The invaluable technical assistance of Dr. R.G.L McCready of CANMET is also gratefully acknowledged.

APPENDIX I

Bacterial Growth Curves

GROWTH RATE EXPERIMENT 1

NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:

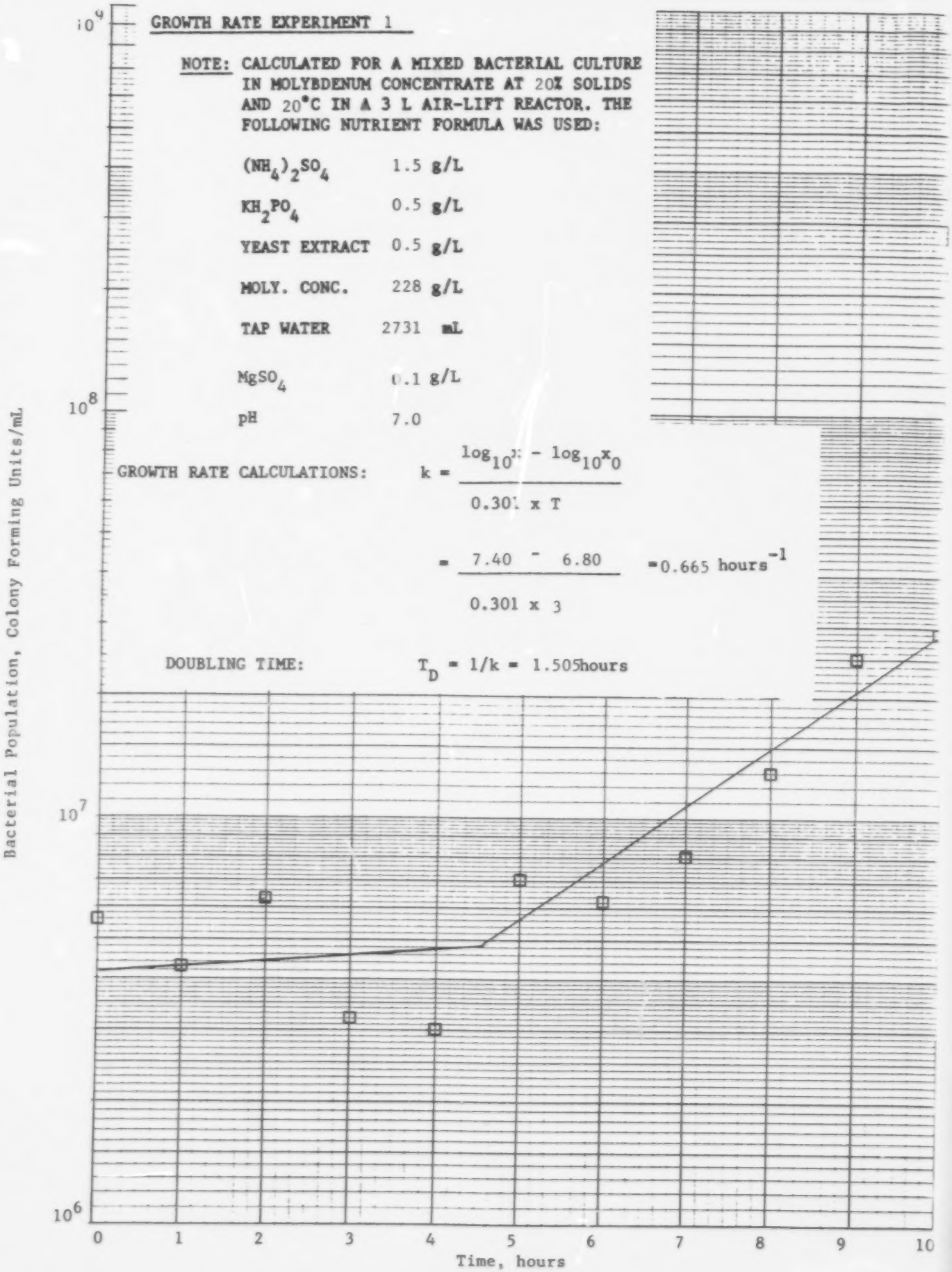
$(NH_4)_2SO_4$	1.5 g/L
KH_2PO_4	0.5 g/L
YEAST EXTRACT	0.5 g/L
MOLY. CONC.	228 g/L
TAP WATER	2731 mL
$MgSO_4$	0.1 g/L
pH	7.0

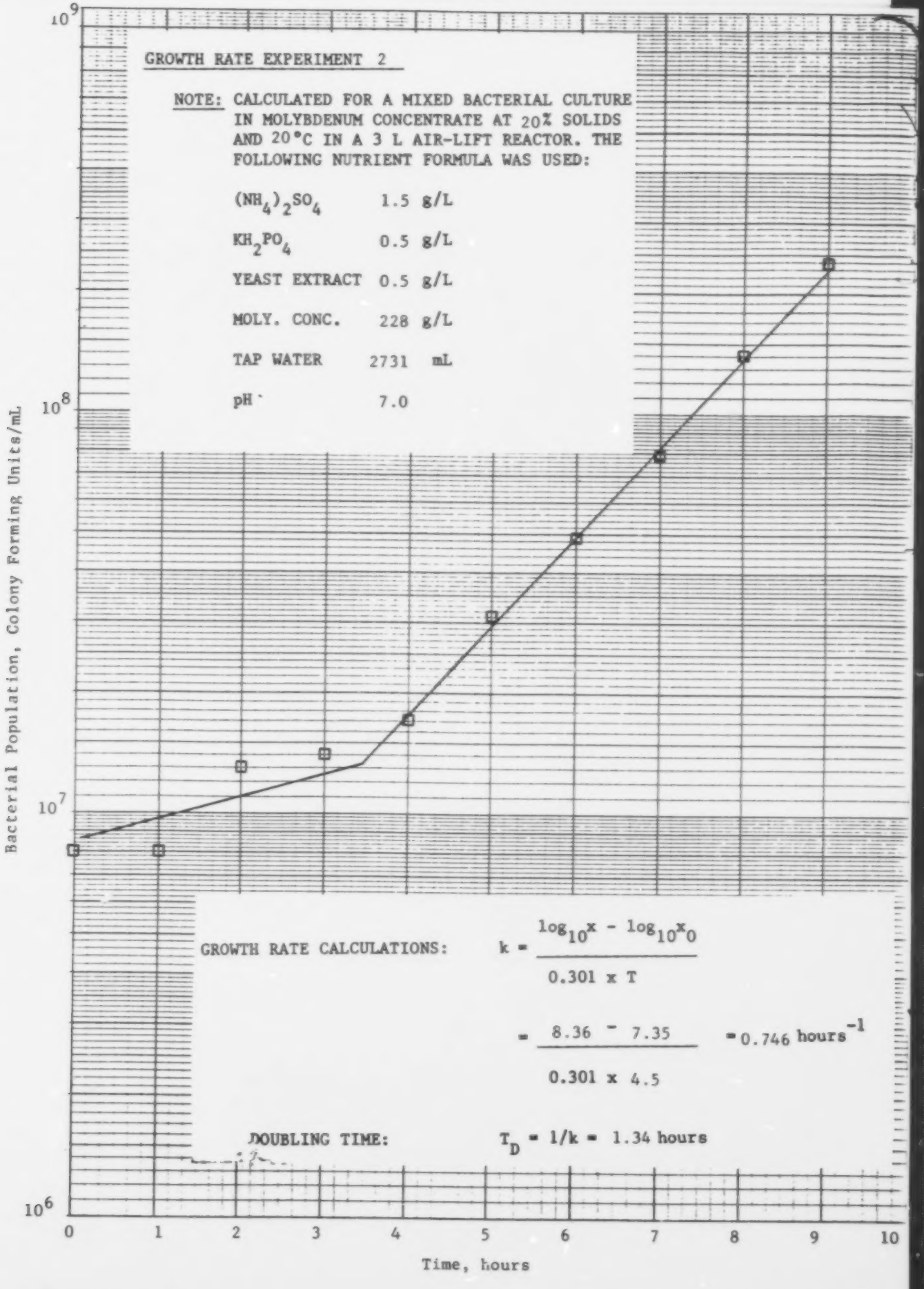
GROWTH RATE CALCULATIONS:

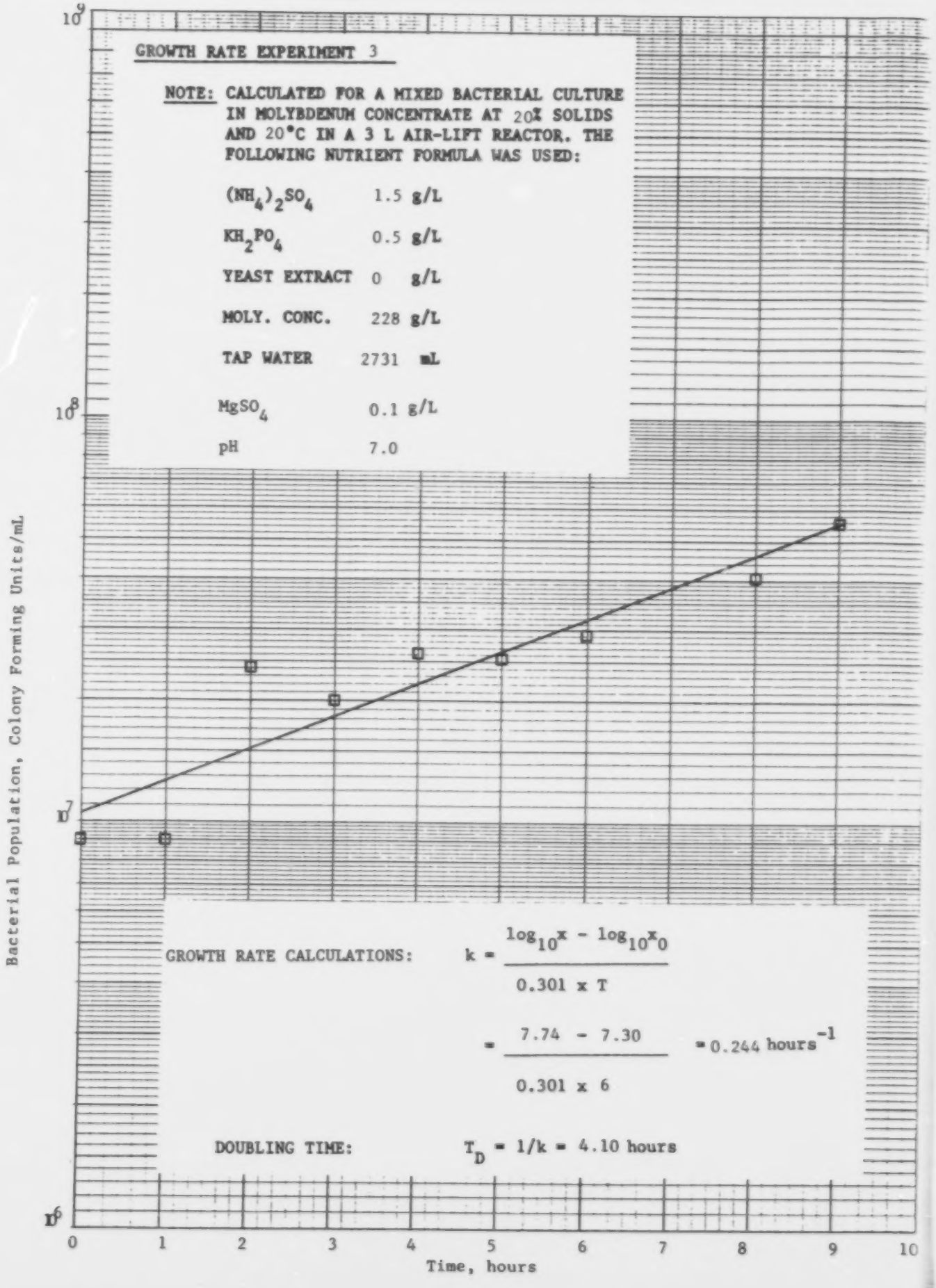
$$k = \frac{\log_{10} x - \log_{10} x_0}{0.301 \times T}$$

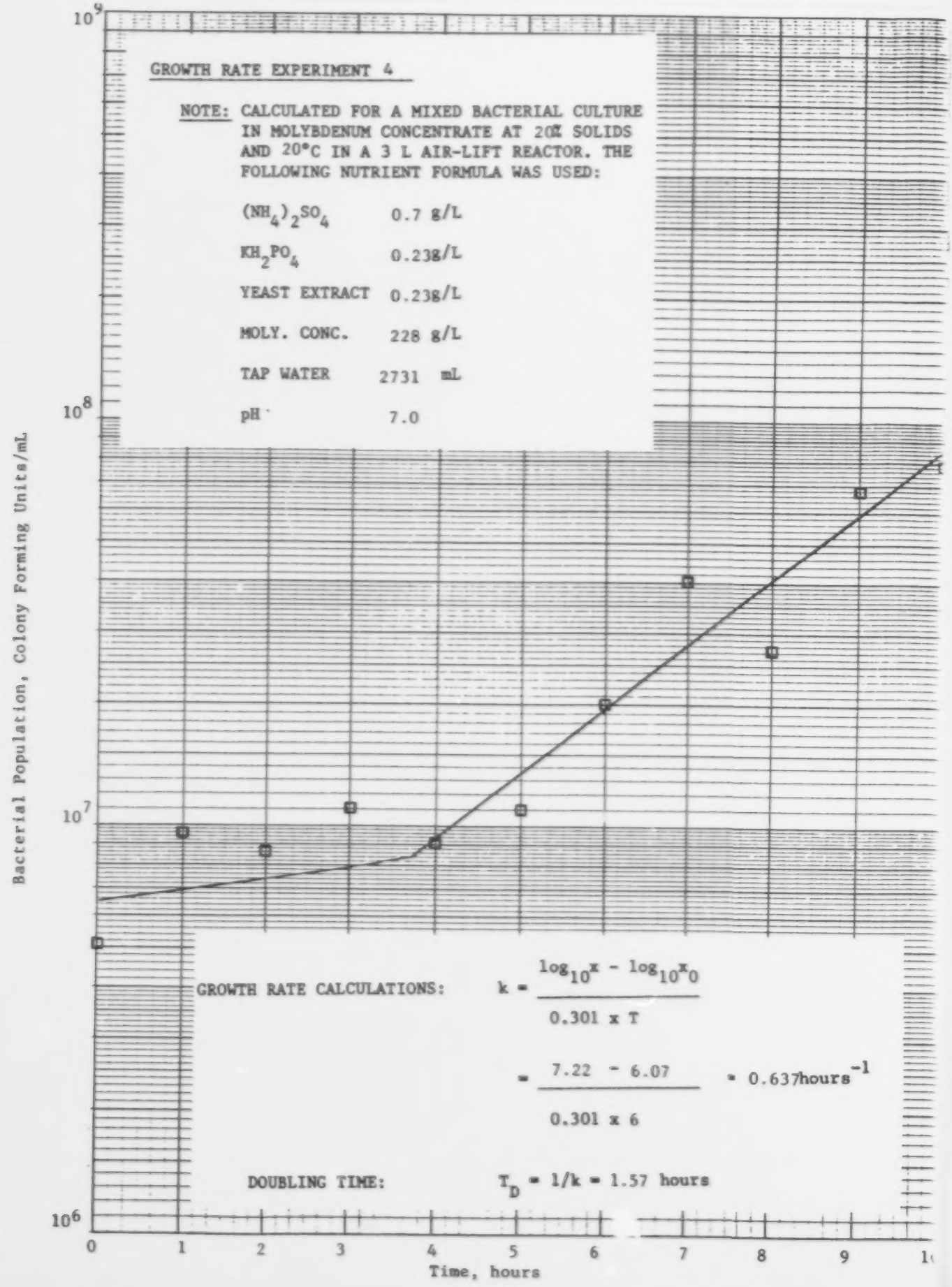
$$= \frac{7.40 - 6.80}{0.301 \times 3} = 0.665 \text{ hours}^{-1}$$

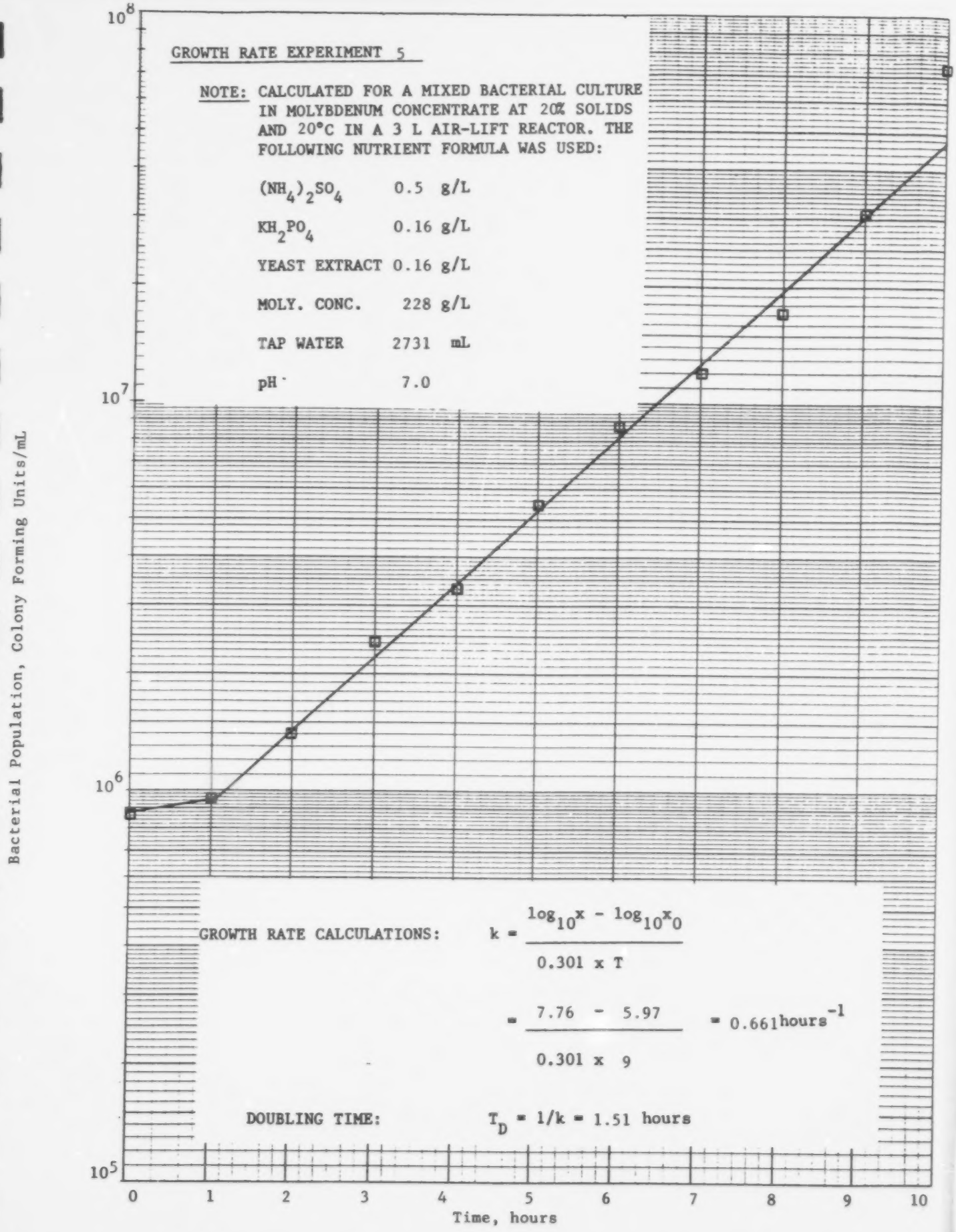
DOUBLING TIME: $T_D = 1/k = 1.505$ hours




GROWTH RATE EXPERIMENT 2
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 1.5 g/L
KH2PO4 0.5 g/L
YEAST EXTRACT 0.5 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
Bacterial Population, Colony Forming Units/mL
10^9
10^8
10^7
10^6
0 1 2 3 4 5 6 7 8 9 10
Time, hours
GROWTH RATE CALCULATIONS: k = (log10 x - log10 x0) / (0.301 x T)
= (8.36 - 7.35) / (0.301 x 4.5) = 0.746 hours^-1
DOUBLING TIME: TD = 1/k = 1.34 hours


GROWTH RATE EXPERIMENT 3
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 1.5 g/L
KH2PO4 0.5 g/L
YEAST EXTRACT 0 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
MgSO4 0.1 g/L
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (7.74 - 7.30) / (0.301 x 6) = 0.244 hours-1
DOUBLING TIME: TD = 1/k = 4.10 hours
Bacterial Population, Colony Forming Units/mL
10^9
10^8
10^7
10^6
0
1
2
3
4
5
6
7
8
9
10
Time, hours


GROWTH RATE EXPERIMENT 4
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.7 g/L
KH2PO4 0.23g/L
YEAST EXTRACT 0.23g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (7.22 - 6.07) / (0.301 x 6) = 0.637hours-1
DOUBLING TIME: TD = 1/k = 1.57 hours
Bacterial Population, Colony Forming Units/mL
Time, hours
10^9
10^8
10^7
10^6
0
1
2
3
4
5
6
7
8
9


GROWTH RATE EXPERIMENT 5
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.5 g/L
KH2PO4 0.16 g/L
YEAST EXTRACT 0.16 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (7.76 - 5.97) / (0.301 x 9) = 0.661 hours-1
DOUBLING TIME: TD = 1/k = 1.51 hours
Bacterial Population, Colony Forming Units/mL
10^8
10^7
10^6
10^5
0
1
2
3
4
5
6
7
8
9
10
Time, hours

GROWTH RATE EXPERIMENT 6

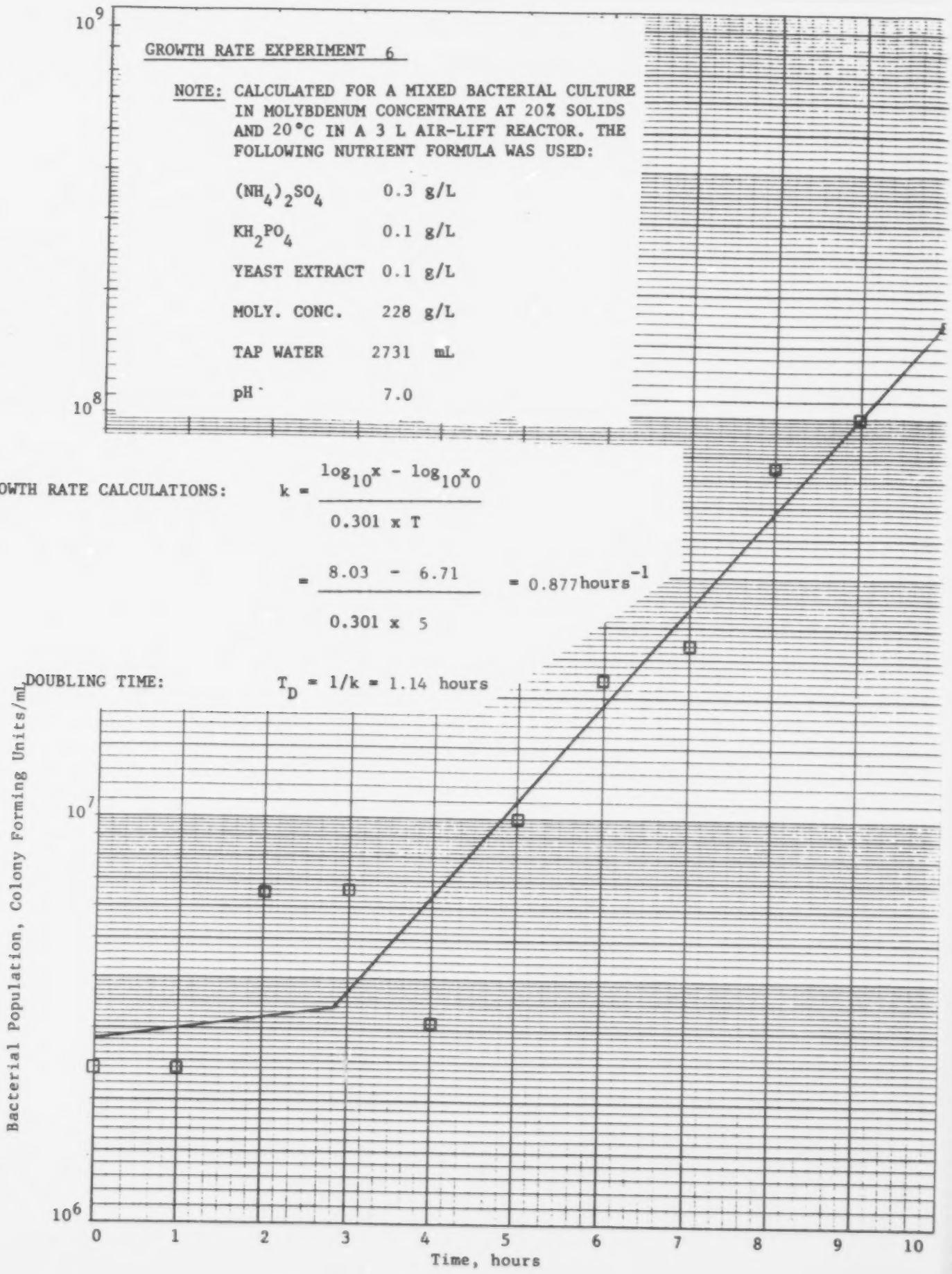
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:

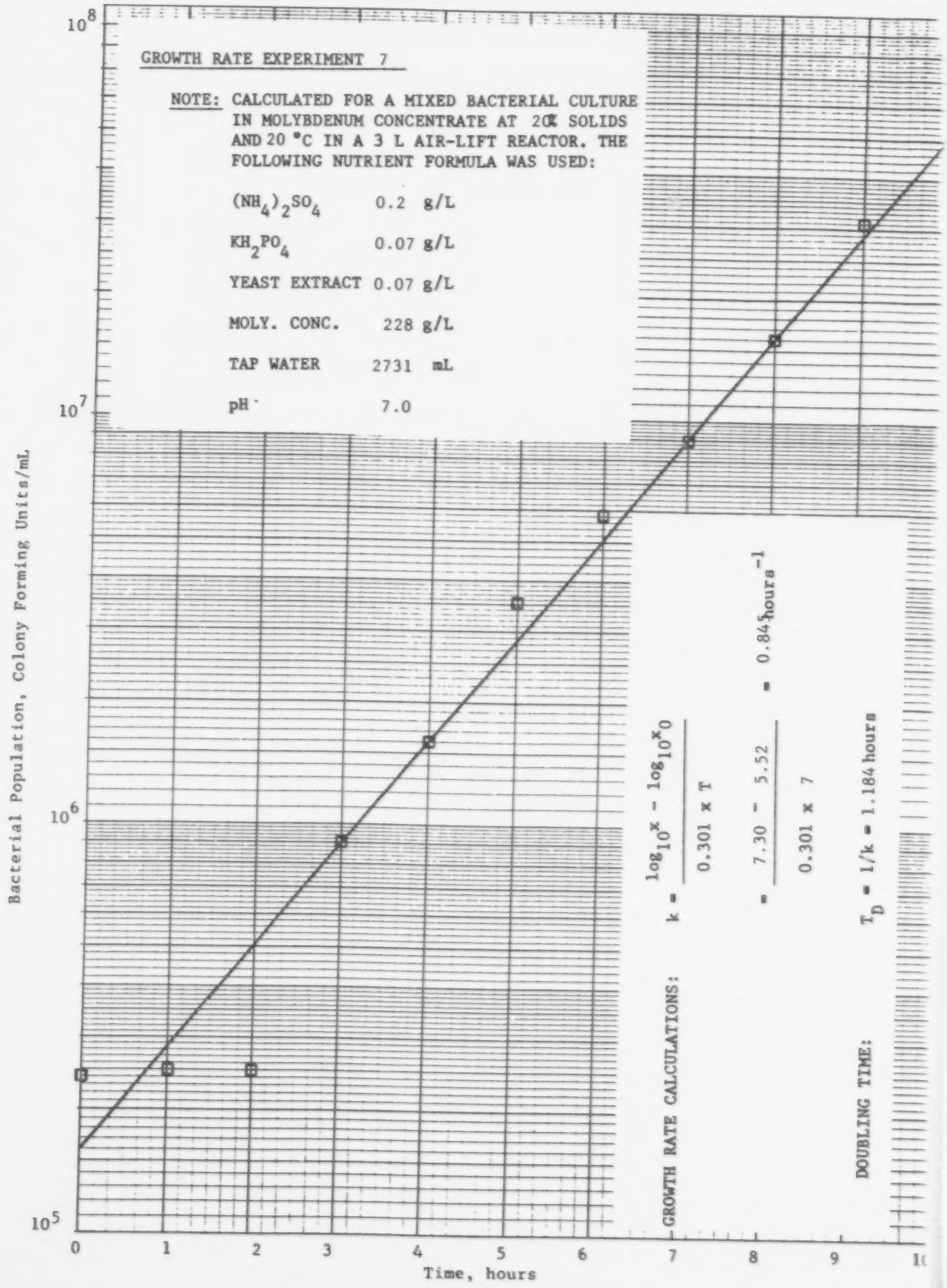
$(NH_4)_2SO_4$	0.3 g/L
KH_2PO_4	0.1 g/L
YEAST EXTRACT	0.1 g/L
MOLY. CONC.	228 g/L
TAP WATER	2731 mL
pH	7.0

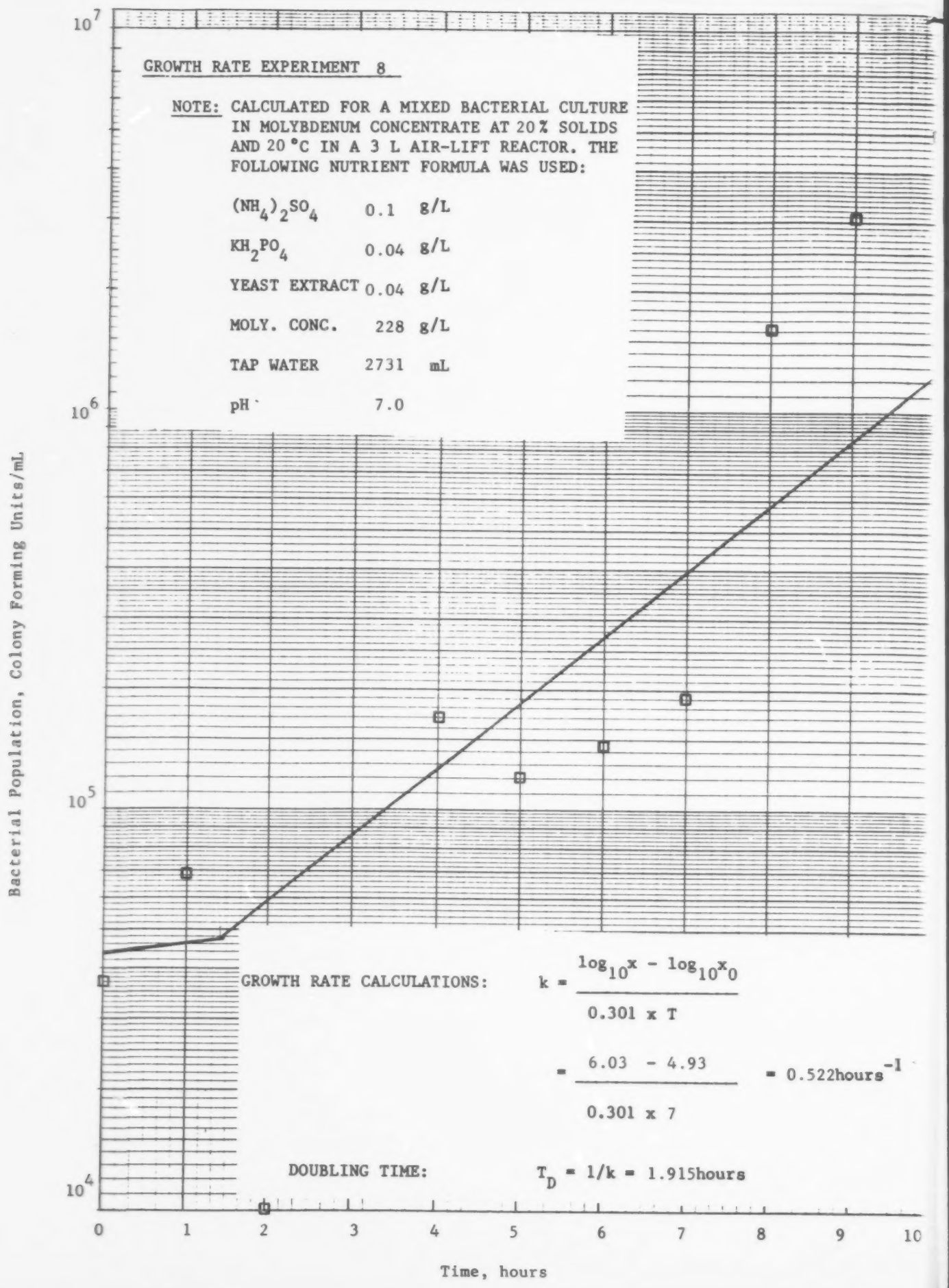
GROWTH RATE CALCULATIONS: $$k = \frac{\log_{10}x - \log_{10}x_0}{0.301 \times T}$$

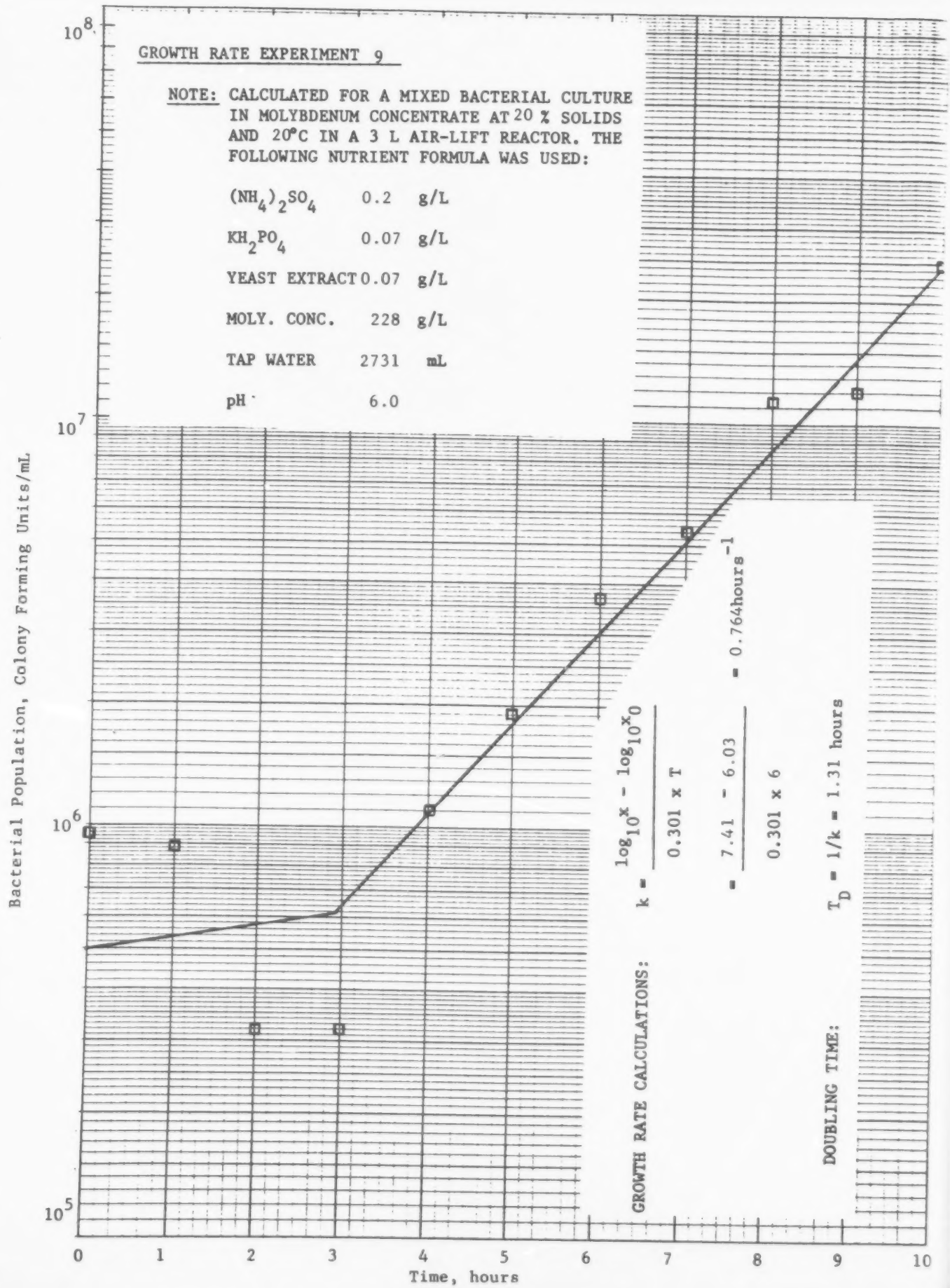
$$= \frac{8.03 - 6.71}{0.301 \times 5} = 0.877 \text{ hours}^{-1}$$

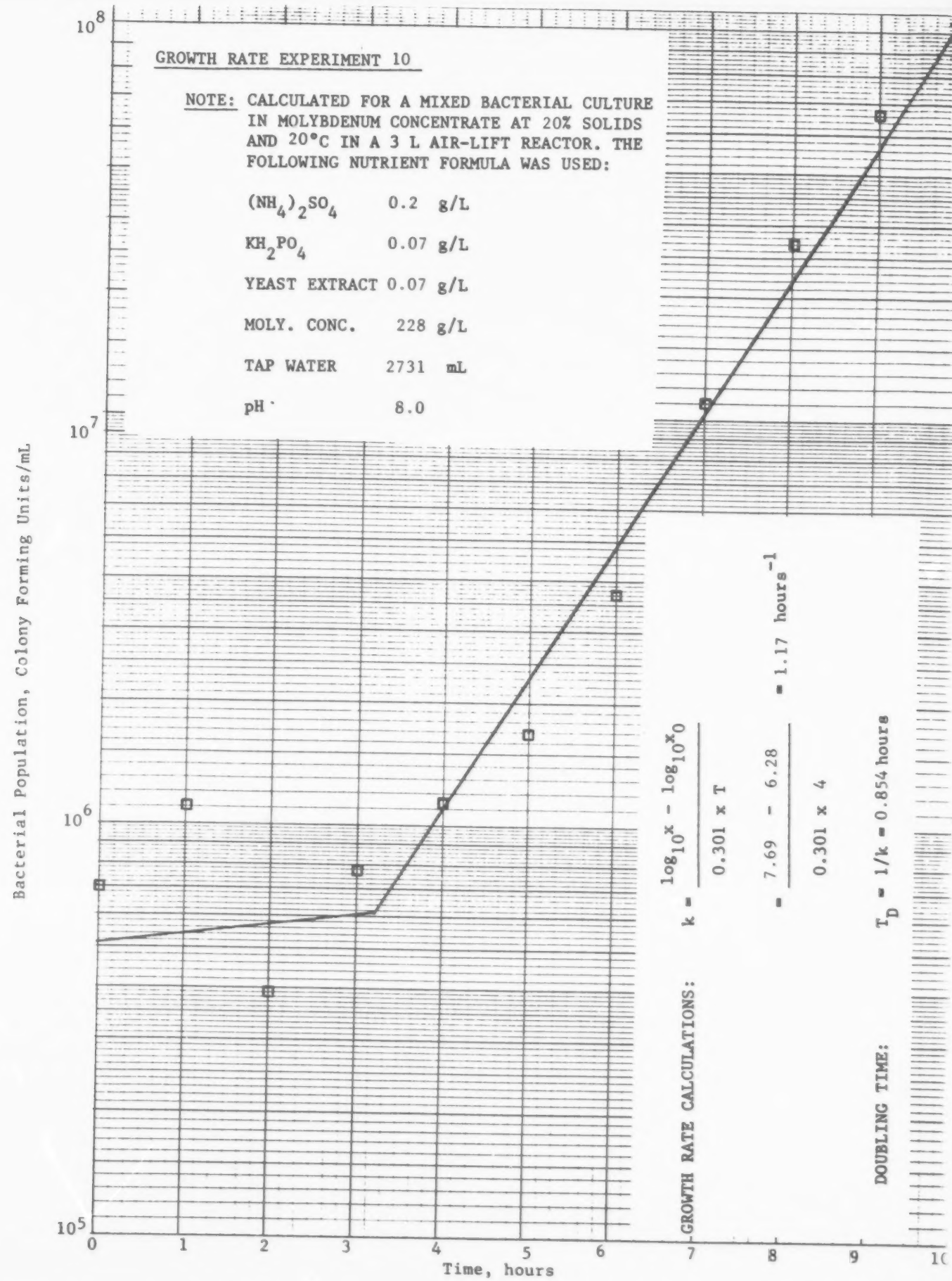
DOUBLING TIME: $T_D = 1/k = 1.14$ hours

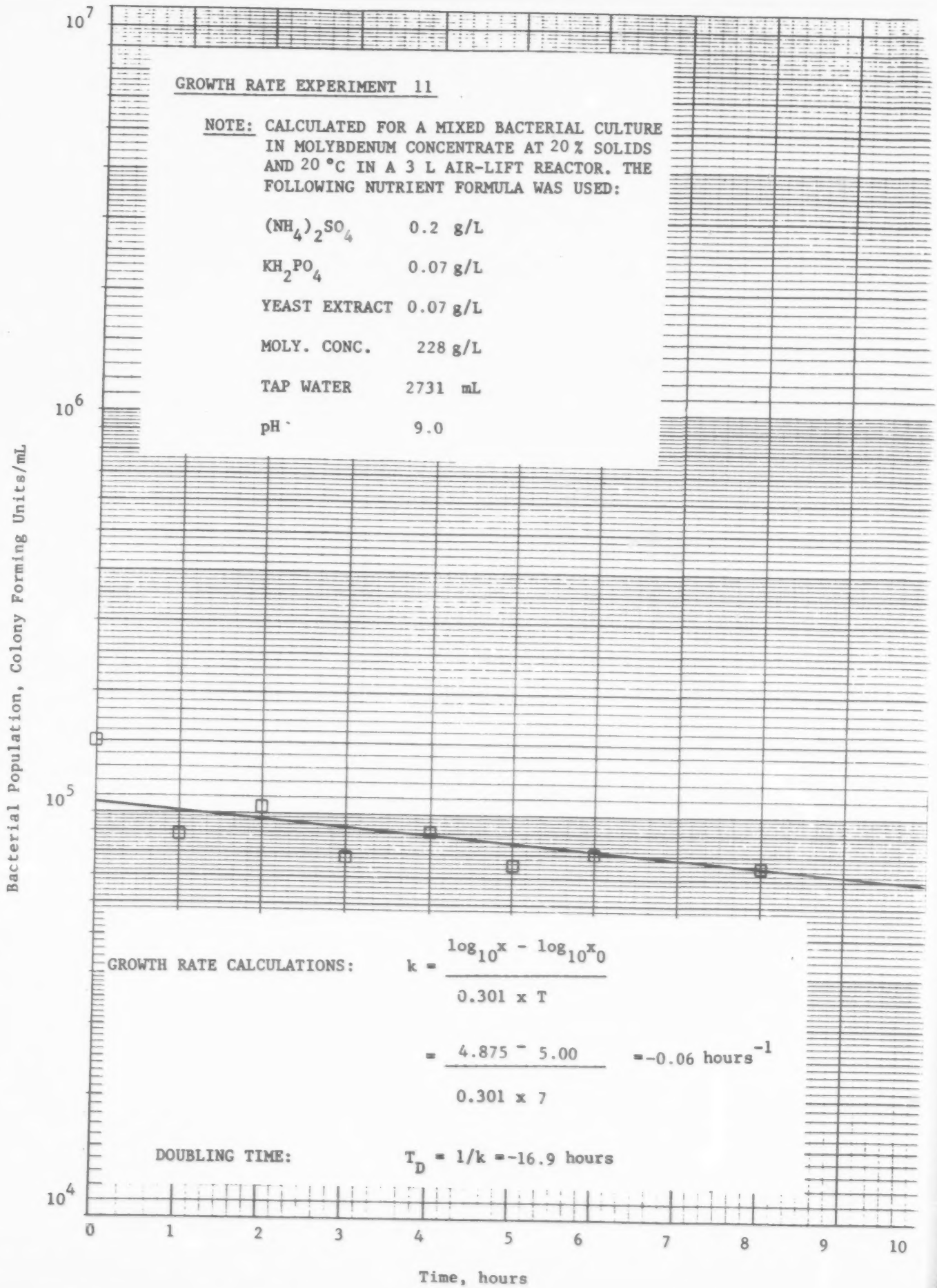


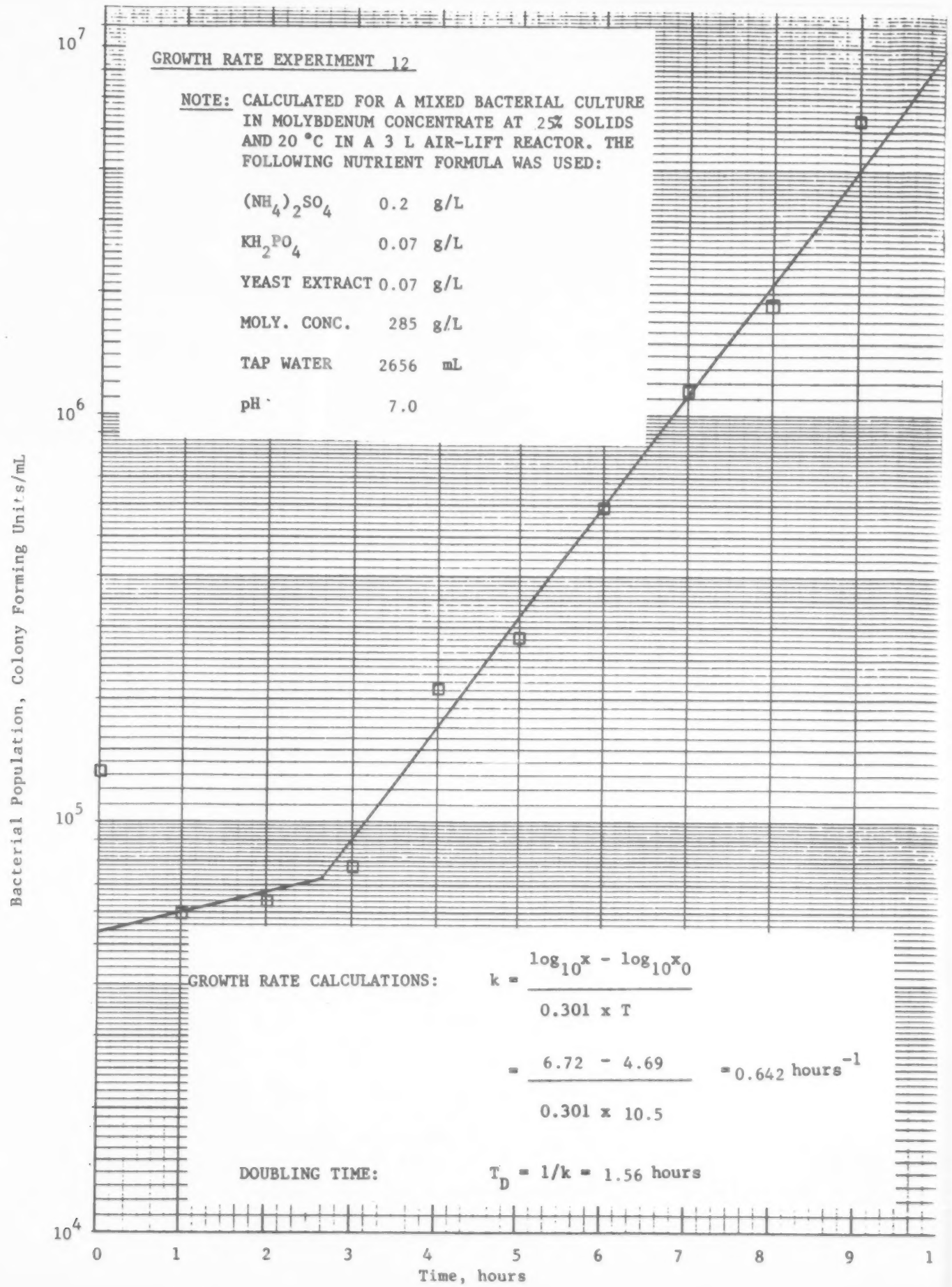

GROWTH RATE EXPERIMENT 7
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20 °C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
Bacterial Population, Colony Forming Units/mL
Time, hours
GROWTH RATE CALCULATIONS:
k = (log10X - log10X0) / (0.301 x T)
= (7.30 - 5.52) / (0.301 x 7) = 0.84 hours-1
DOUBLING TIME:
TD = 1/k = 1.184 hours

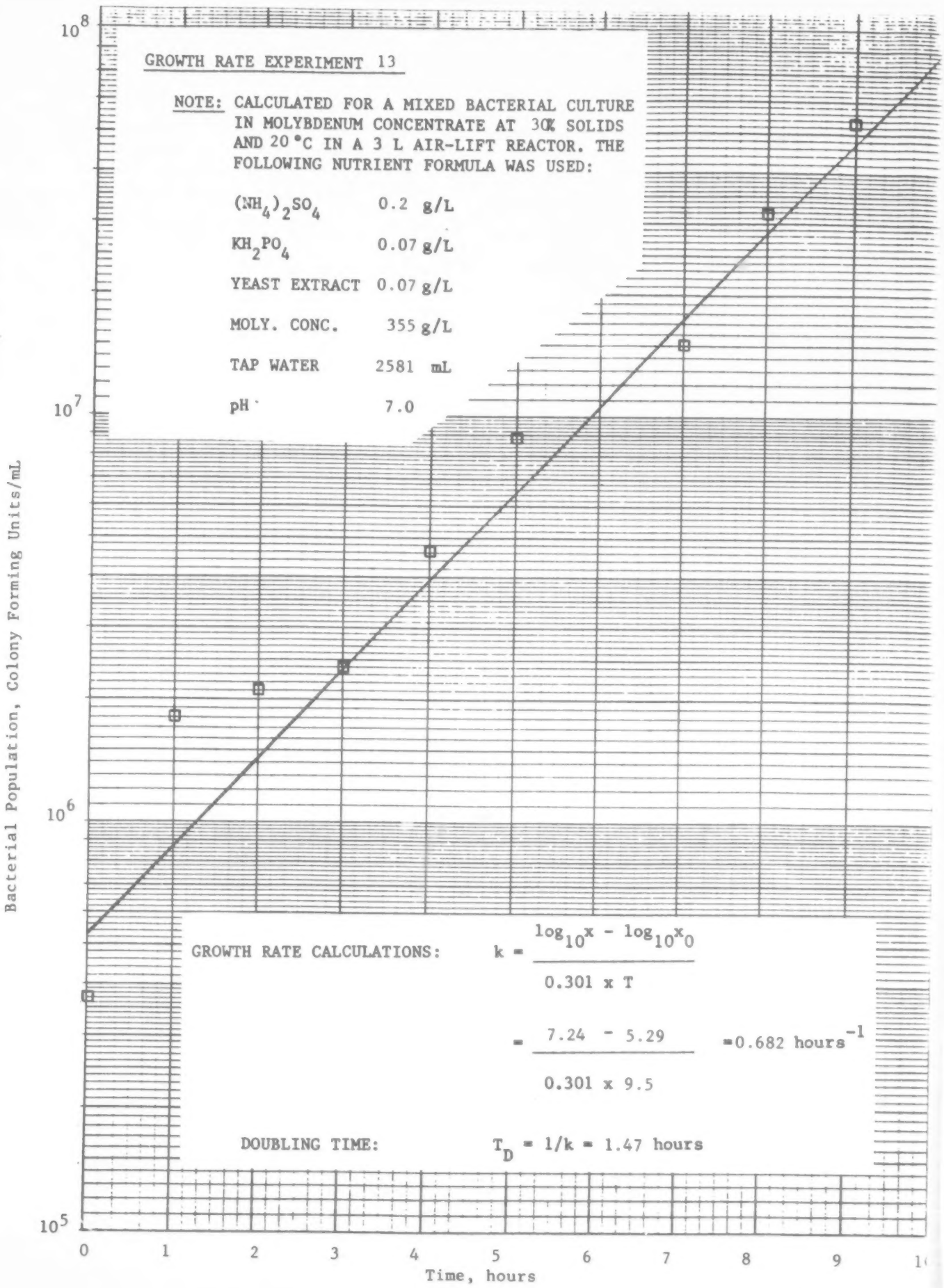

GROWTH RATE EXPERIMENT 8
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20 % SOLIDS AND 20 °C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.1 g/L
KH2PO4 0.04 g/L
YEAST EXTRACT 0.04 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (6.03 - 4.93) / (0.301 x 7) = 0.522hours-1
DOUBLING TIME: TD = 1/k = 1.915hours
Bacterial Population, Colony Forming Units/mL
10^7
10^6
10^5
10^4
0
1
2
3
4
5
6
7
8
9
10
Time, hours

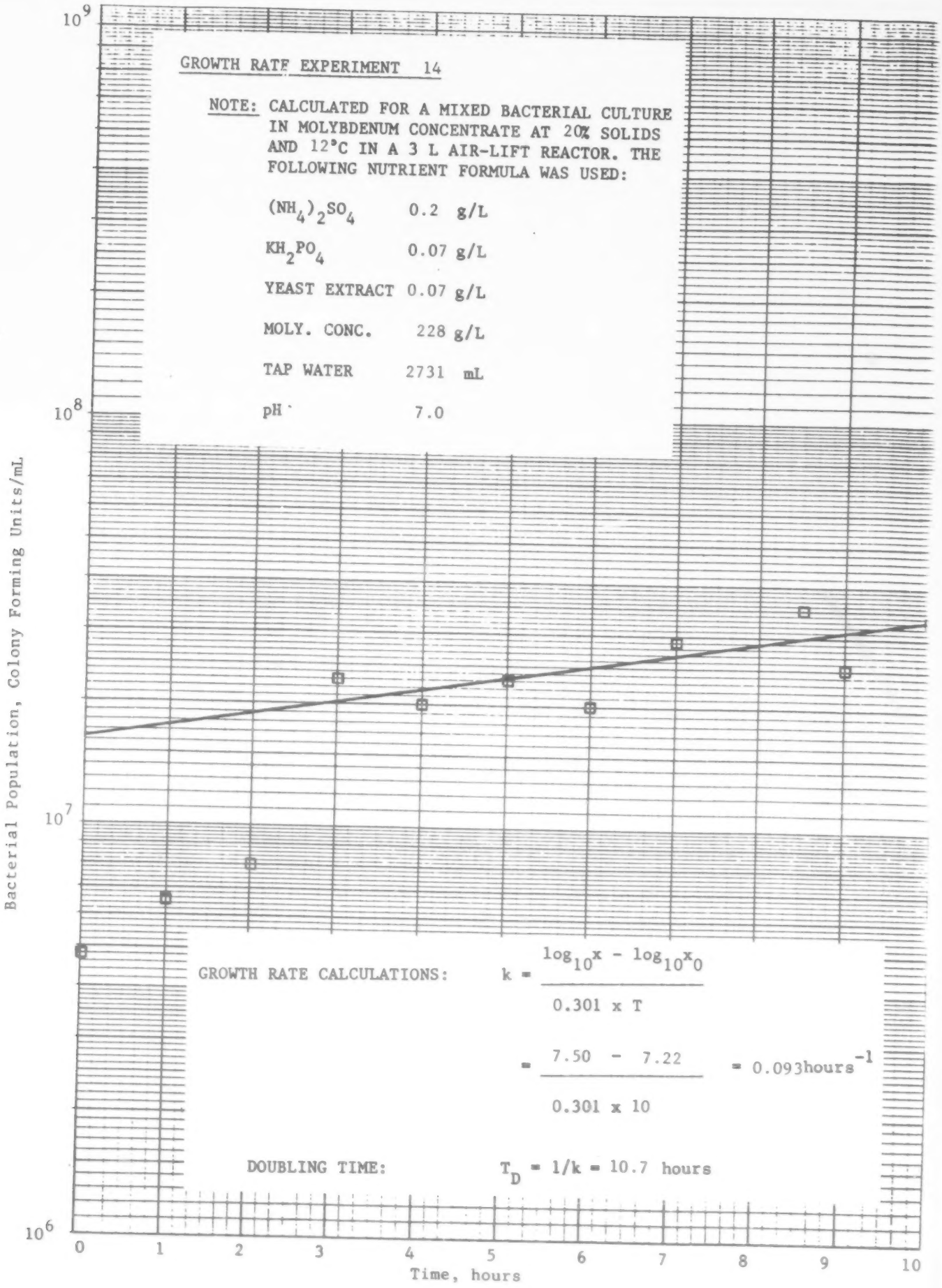

GROWTH RATE EXPERIMENT 9
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20 % SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 6.0
Bacterial Population, Colony Forming Units/mL
Time, hours
GROWTH RATE CALCULATIONS:
k = (log10x - log10x0) / (0.301 x T)
= (7.41 - 6.03) / (0.301 x 6) = 0.764hours-1
DOUBLING TIME:
TD = 1/k = 1.31 hours

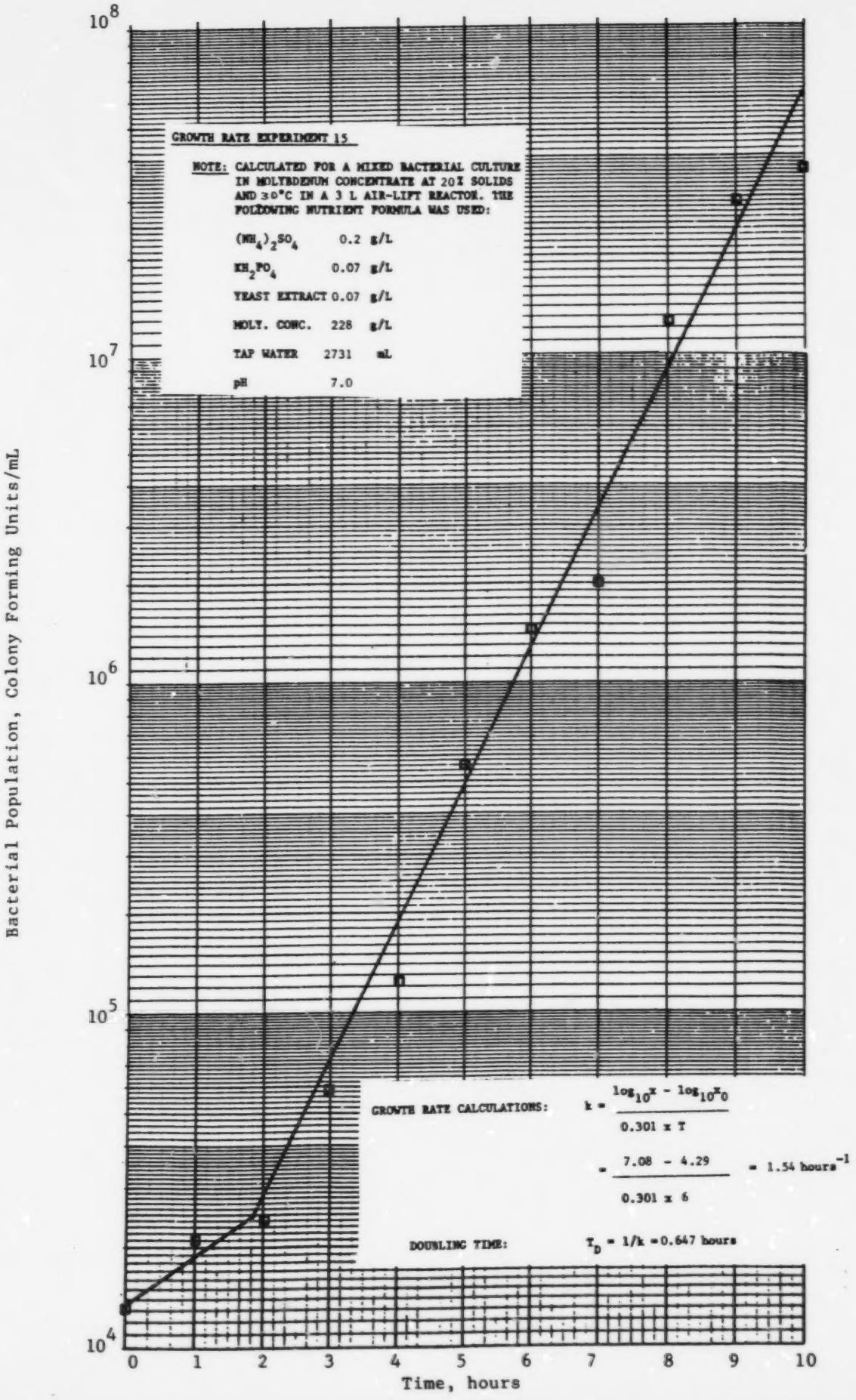

GROWTH RATE EXPERIMENT 10
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 8.0
Bacterial Population, Colony Forming Units/mL
Time, hours
GROWTH RATE CALCULATIONS:
k = (log10 x - log10 x0) / (0.301 x T)
= (7.69 - 6.28) / (0.301 x 4) = 1.17 hours-1
DOUBLING TIME:
TD = 1/k = 0.854 hours

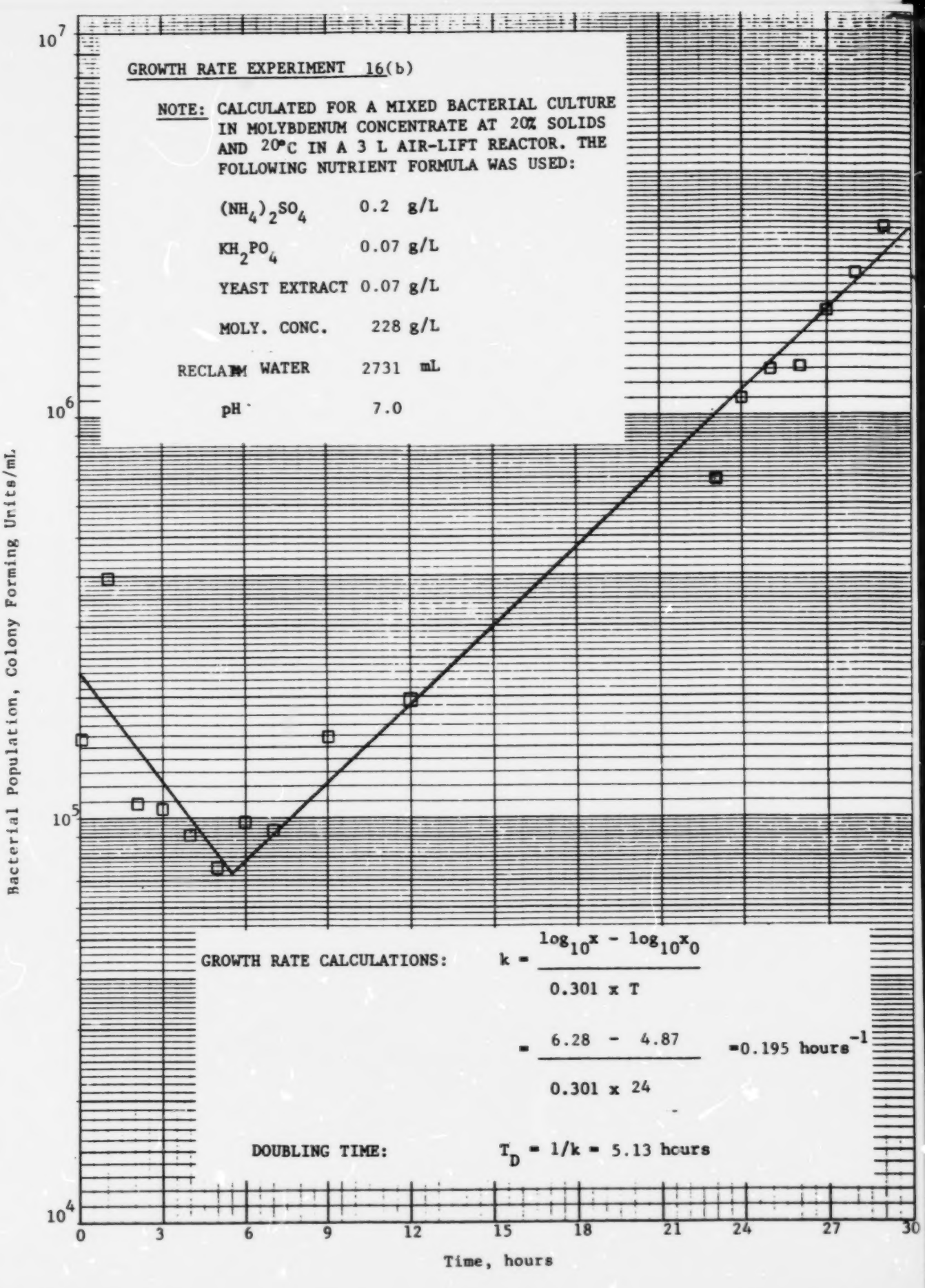

GROWTH RATE EXPERIMENT 11
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20 % SOLIDS AND 20 °C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 9.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (4.875 - 5.00) / (0.301 x 7) = -0.06 hours-1
DOUBLING TIME: TD = 1/k = -16.9 hours
Bacterial Population, Colony Forming Units/mL
10^7
10^6
10^5
10^4
0
1
2
3
4
5
6
7
8
9
10
Time, hours


GROWTH RATE EXPERIMENT 12
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 25% SOLIDS AND 20 °C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 285 g/L
TAP WATER 2656 mL
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / 0.301 x T
= 6.72 - 4.69 / 0.301 x 10.5 = 0.642 hours-1
DOUBLING TIME: TD = 1/k = 1.56 hours
Bacterial Population, Colony Forming Units/mL
10^7
10^6
10^5
10^4
0 1 2 3 4 5 6 7 8 9 1
Time, hours


GROWTH RATE EXPERIMENT 13
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 30% SOLIDS AND 20 °C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 355 g/L
TAP WATER 2581 mL
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (7.24 - 5.29) / (0.301 x 9.5) = 0.682 hours-1
DOUBLING TIME: TD = 1/k = 1.47 hours
Bacterial Population, Colony Forming Units/mL
10^8
10^7
10^6
10^5
0
1
2
3
4
5
6
7
8
9
Time, hours


GROWTH RATE EXPERIMENT 14
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 12°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (7.50 - 7.22) / (0.301 x 10) = 0.093 hours-1
DOUBLING TIME: TD = 1/k = 10.7 hours
Bacterial Population, Colony Forming Units/mL
10^9
10^8
10^7
10^6
0
1
2
3
4
5
6
7
8
9
10
Time, hours


GROWTH RATE EXPERIMENT 15
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 30°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
$(NH_4)_2SO_4$ 0.2 g/L
KH_2PO_4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
TAP WATER 2731 mL
pH 7.0
GROWTH RATE CALCULATIONS: $k = \frac{\log_{10}x - \log_{10}x_0}{0.301 \times T}$
$= \frac{7.08 - 4.29}{0.301 \times 6} = 1.54 \text{ hours}^{-1}$
DOUBLING TIME: $T_D = 1/k = 0.647$ hours
Bacterial Population, Colony Forming Units/mL
10^8
10^7
10^6
10^5
10^4
0 1 2 3 4 5 6 7 8 9 10
Time, hours


GROWTH RATE EXPERIMENT 16(b)
NOTE: CALCULATED FOR A MIXED BACTERIAL CULTURE IN MOLYBDENUM CONCENTRATE AT 20% SOLIDS AND 20°C IN A 3 L AIR-LIFT REACTOR. THE FOLLOWING NUTRIENT FORMULA WAS USED:
(NH4)2SO4 0.2 g/L
KH2PO4 0.07 g/L
YEAST EXTRACT 0.07 g/L
MOLY. CONC. 228 g/L
RECLAIM WATER 2731 mL
pH 7.0
Bacterial Population, Colony Forming Units/mL
10^7
10^6
10^5
10^4
0
3
6
9
12
15
18
21
24
27
30
Time, hours
GROWTH RATE CALCULATIONS: k = (log10x - log10x0) / (0.301 x T)
= (6.28 - 4.87) / (0.301 x 24) = 0.195 hours^-1
DOUBLING TIME: TD = 1/k = 5.13 hours

APPENDIX II

Method for Organic Carbon Determination

Method for Organic Carbon Determination

1. Weigh out 5.000 g of dry solids.
2. Place into a clean 100 mL beaker.
3. Add approximately 50 mL of benzene.
4. Place on a hot plate on low heat (50-80°C) for 5 minutes, mixing every 30 seconds.
5. Decant the benzene and filter through a filter paper; the filtrate being collected in a clean 250 mL flask.
6. Repeat steps 3 to 5 twice.
7. Evaporate the benzene in a clean, pre-weighed 100 mL beaker at low heat (80-100°C).
8. Weigh the hydrocarbon residue. Calculate the percentage of benzene extractable hydrocarbon in the feed sample.

APPENDIX III

Experimental Work Program
Continuous Bio-treatment of Molybdenite
Concentrate in a 3L Air-Lift Reactor

February 5, 1987

D. Hoppe
Microbiologist

1044A

TABLE OF CONTENTS

1.0 PROGRAM OBJECTIVE

2.0 PROCESS DESCRIPTION

3.0 MATERIAL

4.0 EXPERIMENTAL PROCEDURES

4.1 Nutrient Preparation
4.2 Process Start-up
4.3 Continuous Decantation Start-up
4.4 Process Shut-down and Maintenance
4.5 Required Analysis
4.5.1 Decantation Rate
4.5.2 Bacterial Populations
4.5.3 Temperature, Redox Potential and pH Readings
4.5.4 Solids Analysis
4.6 Tabulation of Data

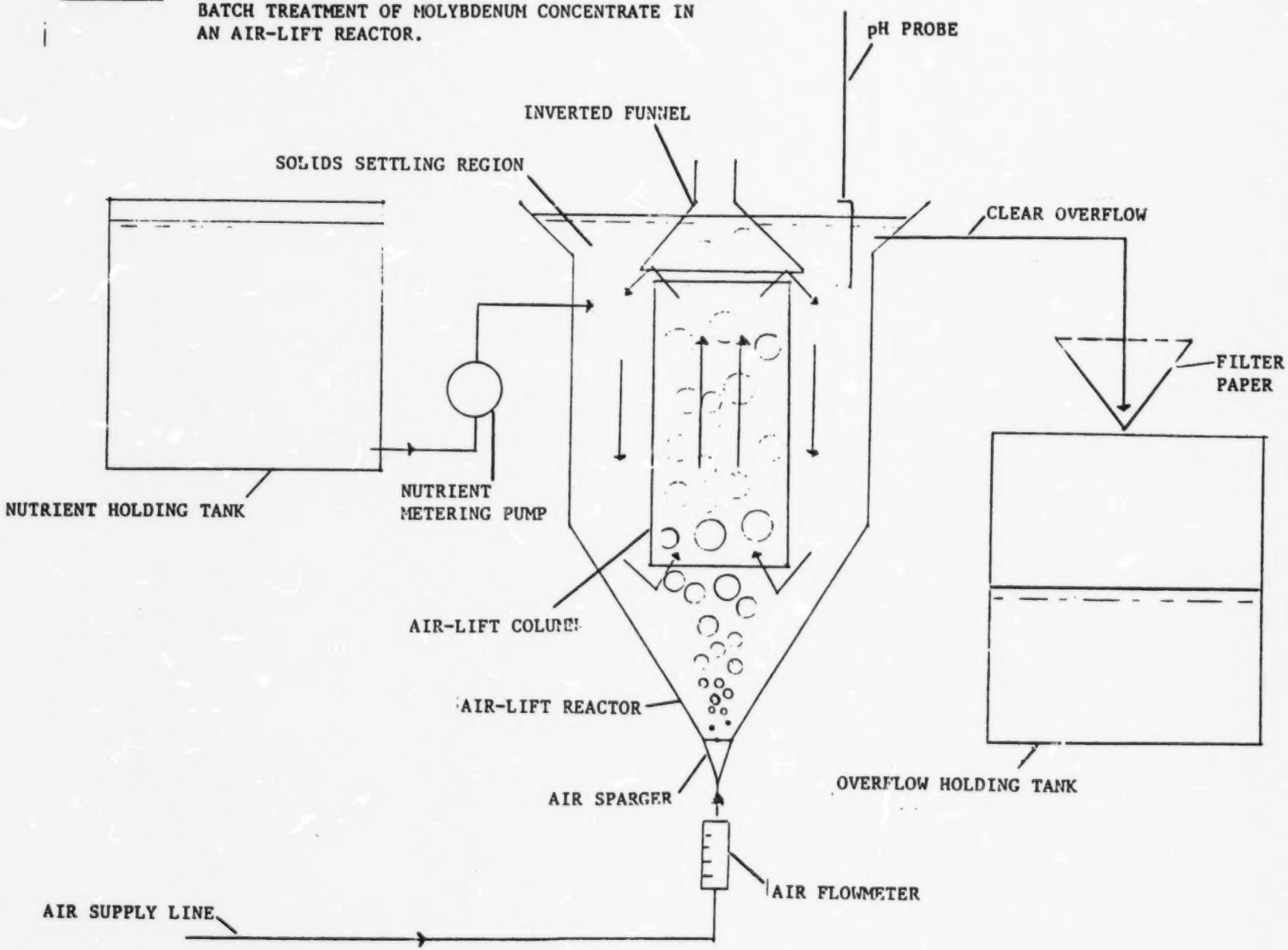
1.0 PROGRAM OBJECTIVE

To biologically treat a hydrocarbon contaminated molybdenum flotation concentrate so as to degrade and thus remove the "sticky" asphalt-like hydrocarbon from the solids. This will be done in a batch-continuous decantation mode to maintain an optimum biological activity. Conventional metallurgical techniques will subsequently be used to separate the carbon from the bio-treated concentrate to reach product specifications. The key parameters to be established is how much "sticky" hydrocarbon can be removed from the system and what the molybdenum losses are in this operation.

2.0 PROCESS DESCRIPTION

The process flowsheet is illustrated in Figure 1. The air-lift reactor will hold a slurry of molybdenite concentrate in bacterial nutrient solution. The reactor is innoculated with a bacterial culture acclimated to molybdenite concentrate. The nutrient metering pump adds nutrient to the treatment vessel at a predetermined rate. Bacterial biomass and suspended particulate solids (carbon, molybdenum and degradation products) are continuously decanted from the reactor via the solids settling region. The bulk of the solids remain in the treatment vessel throughout the process. The treatment is expected to take five to seven days. Bacterial populations, pH, temperature and redox potential readings will be monitored throughout the experiment. The nutrient solution feed rate will be adjusted to maintain a constant bacterial population. Following the experiment, the amount of carbon removed and the amount of molybdenum lost by decantation will be determined. Optimum process conditions will be noted for future testwork.

FIGURE 1. REACTOR CONFIGURATION FOR A CONTINUOUSLY FED, BATCH TREATMENT OF MOLYBDENUM CONCENTRATE IN AN AIR-LIFT REACTOR.



3.0 MATERIAL

A synthetic composite of hydrocarbon contaminated molybdenite concentrate will be treated. The concentrate contains 13.50% C, 13.90% Mo, 4.93% Cu and 7.23% Fe.

4.0 EXPERIMENTAL PROCEDURES

4.1 Nutrient Preparation

Prepare 80 L of nutrient solution of the following composition in a clean vessel:

24 g $(NH_4)_2\ SO_4$
8.4 g $KH_2\ PO_4$
8.4 g Yeast Extract
120 L tap water

Adjust the pH to 7.50.

4.2 Process Start-Up

The following equipment is needed prior to start-up:

1. 1000 g molybdenum flotation concentrate
2. 120 L nutrient solution in 45 gallon drum
3. Overflow holding tank (10 gallon pail)
4. 3 L air-lift reactor
5. Air flowmeter (optional)
6. Nutrient metering pump
7. Plastic tubing
8. Filter paper
9. pH electrode
10. Thermometer
11. Redox electrode

1. Roll the concentrate sample thoroughly and remove 100 g for assay purposes. Analyze for total carbon, organic carbon, molybdenum, copper and iron.

2. Calibrate the nutrient metering pump so that 7.5, 10 and 12.5 mL/minute can be quickly registered.

3. Weigh out 855 g of concentrate in a 4 L beaker. Add 2415 mL of nutrient solution and agitate until homogeneously mixed. Adjust pH to 7.0 with conc. H_2SO_4 (approximately 1 mL). Add 150 mL of bacterial solution to the beaker and agitate for 30 seconds. Add the contents of the beaker to the air-lift reactor. Turn on the air flow line and place the inverted funnel on the reactor. Record the pH, temperature and bacterial population. Adjust the air flow so that the settling region of the reactor remains undisturbed. Operate the reactor for 12 hours.

4.3 Start-up of Continuous Decantation

Start the nutrient metering pump at 10 mL/minute. Record the pH, temperature, redox potential and bacterial population. Take the above readings at timed intervals (i.e. 2 hours) for the duration of the experiment (3 to 7 days). If the bacterial population drops below 10^6 organisms/mL or rises above 10^8 organisms/mL, adjust the nutrient metering pump 5% slower or faster, respectively. The bacterial population should be adjusted in this manner for the duration of the experiment.

4.4 Process Shut Down and Maintenance

On a day-to-day basis, record the volume of the reactor overflow and filter the overflow through a buchner funnel. Dry, weigh and assay the solids for total and organic carbon, molybdenum, iron and copper.

At the completion of the experiment, shut off the nutrient metering pump and the air supply line. Filter, dry and assay the reactor solids for total and organic carbon, molybdenum, iron and copper.

4.5 Process Monitoring

The following parameters will be measured.

4.5.1 Decantation Rate

Record the decantation rate using a 25 mL graduated cylinder. Adjust the metering pump if the decantation rate is not at the previous rate.

4.5.2 Bacterial Populations

Bacterial populations are to be counted at two hour intervals using hemacytometer count. Take 10 mL of solution from the reactor and place in a centrifuge tube. Centrifuge at 3/4 speed (2800 rpm) for one minute. Place 2 mL in a clean test tube and place 1 mL in a methylene blue 9 mL blank. Vortex mix for 5 seconds. Fill the hemacytometer chamber. Use the microscope at high power (1250x oil immersion). Count with the undiluted sample. If there are greater than 50 organisms per single square, do not continue counting. Clean the counting chamber and load with the tenfold dilution. Count 4 16-square grids and calculate the average.

The hemacytometer count is calculated as follows:

bacteria/16 squares x 250,000 x dilution = bacterial count/mL

After recording the hemacytometer count, replace the solids from the centrifuge tube back into the reactor.

4.5.3 Temperature, Redox Potential and pH Readings

At two-hour intervals record the temperature in the reactor vessel. If the temperature drops below 20°C, heat the reactor with the 60 watt lamp provided until the temperature reaches 20°C. Record the pH of the reactor at two-hour intervals with a combination electrode standardized to pH 7.0. If the pH drops below 6.5 or rises above 7.5 adjust the pH of the nutrient supply with 1.0 N NaOH or conc. H_2SO_4 respectively. Record the redox potential at two-hour intervals with a standardized platinum electrode.

4.5.4 Solids Analysis

Solids analysis to be completed on the following substances:

1. untreated flotation concentrate
2. treated flotation concentrate
3. overflow solids

Assay the above substances for total carbon, organic carbon, molybdenum, copper and iron.

4.6 Tabulation of Data

Record data in the following table provided.

SUMMARY DATA

Solids	% C_{tot}	% C_{org}	% Mo
1. Untreated Conc.			
2. Treated Conc.			
3. Overflow Solids			

Volume of Overflow =

Bacterial Count in Overflow =

APPENDIX IV

Flotation Test Data

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: FEED MATERIAL: MOLYBDENUM CONCENTRATE **WEIGHT-GR:** 200 **TEST NO:** OF1

SUBJECT OF TEST: ORE FLOTATION; DEPRESS MOLYBDENITE, FLOAT HYDROCARBON **DATE:** MARCH 26, 1987

TEST BY DH

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	ORZAN 'A'							
CONDITION	5	20	11.90	250 g cell	1300	12.1	3.0							
FLOAT 1	3				1300									-fine bubbles,brittle,
FLOAT 2	3				1500									-not much weight pulled
FLOAT 3	3				1500									- gray colour

PRODUCT	Wt. gr.	Wt. %	ASSAYS				METAL CONTENT				DISTRIBUTION %				REMARKS
			%C	%Mo	%Cu	%Fe					C	Mo	Cu	Fe	
CONC.	26.41	15.69	19.2	15.7	8.4	9.45					20.07	11.86	21.03	16.60	
TAIL	168.31	84.31	12.0	18.3	4.95	7.45					79.93	88.14	78.97	83.40	
TOTAL	194.72	100.00	(12.98)	(17.95)	(5.42)	(7.72)					100.00	100.00	100.00	100.00	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: TREATED COMPOSITE: TESTS #2, 3 **WEIGHT-GR:** 200 **TEST NO:** OT1

SUBJECT OF TEST: ORE FLOTATION: DEPRESS MOLYBDENITE, FLOAT HYDROCARBON **DATE:** MARCH 26, 1987

TEST BY DH

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	ORTAN A							
CONDITION	5	20	11.90	250g cell	1300	8.0	3.0							
FLOAT 1	3				1300									-good pull, slightly less metal visible
FLOAT 2	3				1500									
FLOAT 3	3				1500									- large, thick black bubbles

PRODUCT	Wt. gr.	Wt. %	ASSAYS				METAL CONTENT				DISTRIBUTION %				REMARKS
			%C	%Mo	%Cu	%Fe					C	Mo	Fe	Cu	
CONC.1	23.62	11.87	13.5	13.7	9.60	11.85					10.60	7.99	19.24	21.29	
CONC. 2	8.82	4.43	14.5	15.2	8.70	10.05					4.25	4.68	6.09	7.20	
CONC. 3	10.15	5.10	13.4	16.0	7.95	10.10					4.52	4.01	7.05	7.58	
TOTAL CONC.	42.59	21.40	13.68	14.56	9.02	11.01					19.37	16.68	32.38	36.07	
TAIL	156.44	78.60	15.5	19.0	4.35	6.30					80.63	83.32	67.62	63.93	
TOTAL	199.03	100.00	(15.11)	(18.05)	(5.35)	(7.31)					100	100	100	100	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: FEED MATERIAL :MOLYBDENUM CONCENTRATE **WEIGHT-GR:** 200 **TEST NO:** OF2

SUBJECT OF TEST: ORE FLOTATION: DEPRESS MOLYBDENUM, FLOAT HYDROCARBON **DATE:** MARCH 30, 1987

TEST BY

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	ORZAN 'A'							
CONDITION	5	20	11.90	250g ce	1/1500	12.1	6.0							-fine, black bubbles
FLOAT 1	3				1500									-not much weight pulled,
FLOAT 2	3				1500									-poor flotation response
FLOAT 3	3				1500									

PRODUCT	Wt. gr.	Wt. %	ASSAYS %C	%Mo	%Cu	%Fe	METAL CONTENT				DISTRIBUTION % C	Mo	Cu	Fe	REMARKS
CONC.	35.11	18.49	20.5	13.9	7.46	10.12					20.09	17.66	25.71	23.32	
TAIL	154.78	81.51	18.5	14.7	4.89	7.55					79.91	82.34	74.29	76.68	
TOTAL	189.89	100.00	18.87	14.55	5.36	8.03					100	100	100	100	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: TREATED MATERIAL: TESTS# 2, 3 **WEIGHT-GR:** 200 **TEST NO:** OT2

SUBJECT OF TEST: ORE FLOTATION, DEPRESS MOLYBDENITE, FLOAT HYDROCARBON **DATE:** MARCH 30, 1987

TEST BY

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	ORZAN A							
CONDITION	5	20	11.9	250g cell	1500	8.0	6.0							- thick, stiff black
FLOAT 1	3				1500									bubbles. Good flotation
FLOAT 2	3				1500									characteristics.
FLOAT 3	3				1500									

PRODUCT	Wt. gr.	Wt. %	ASSAYS				METAL CONTENT				DISTRIBUTION %				REMARKS
			%C	%Mo	%Cu	%Fe					C	Mo	Cu	Fe	
PULL 1	24.18	12.11	14.0	14.4	9.34	11.98					10.82	7.89	21.46	18.47	
PULLS 2,3	17.62	8.83	15.0	16.6	8.39	10.96					8.45	6.63	14.05	12.31	
TOTAL CONC.	41.80	20.94	14.42	15.33	8.94	11.55					19.27	14.52	35.51	30.78	
TAIL	157.80	79.06	16.0	23.9	4.30	6.88					80.73	85.48	64.49	69.22	
TOTAL	199.60	100.0	15.67	22.10	5.27	7.86					100.0	100.0	100.0	100.0	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: FEED MATERIAL:MOLYBDENUM CONCENTRATE **WEIGHT-GR:** 200 **TEST NO:** AF1

SUBJECT OF TEST: ORE FLOTATION: FLOAT MOLYBDENITE, DEPRESS HYDROCARBON **DATE:** MARCH 26, 1987

TEST BY

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	AERO 633							
CONDITION	10	20	8.50	250g cell	1500	0.6	0.2							-sticky, brittle froth
FLOAT	5				1500									-trapped carbon noticeable
														-large, stiff bubbles.

PRODUCT	Wt. gr.	Wt. %	ASSAYS %C	%Mo	%Cu	%Fe	METAL CONTENT				DISTRIBUTION % C	Mo	Cu	Fe	REMARKS
CONC.	57.23	29.53	7.0	14.1	6.35	9.0					10.97	21.96	34.51	34.7	
TAIL	136.55	70.47	23.8	21.0	5.05	7.15					89.03	78.04	65.49	65.26	
TOTAL	193.78	100.0	18.84	18.96	5.43	7.65					100.0	100.0	100.0	100.0	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: TREATED CONCENTRATE: TESTS # 2, 3 **WEIGHT-GR:** 200 **TEST NO:** AT1

SUBJECT OF TEST: ORE FLOTATION: FLOAT MOLYBDENITE, DEPRESS HYDROCARBON **DATE:** MARCH 26, 1987

TEST BY

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	AERO 633							
CONDITION	10	20	8.50	250g cell	1500	0.9	0.2							-sticky, brittle froth
FLOAT	5				1500									-some trapped carbon
														noticable
														- large bubbles

PRODUCT	Wt. gr.	Wt. %	ASSAYS				METAL CONTENT				DISTRIBUTION %				REMARKS
			%C	%MO	%Cu	%Fe					C	Mo	Fe	Cu	
CONC.	49.03	25.28	14.5	15.2	8.90	11.10					20.96	21.84	41.47	36.95	
TAIL	144.93	74.72	18.5	18.4	4.25	6.35					79.04	78.16	58.53	63.05	
TOTAL	193.96	100.0	17.49	17.59	5.43	7.53					100.0	100.0	100.0	100.0	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: FEED MATERIAL:MOLYBDENUM CONCENTRATE **WEIGHT-GR:** 200 **TEST NO:** AF2

SUBJECT OF TEST: ORE FLOTATION: FLOAT MOLYBDENITE, DEPRESS HYDROCARBON **DATE:** MARCH 27, 1987

TEST BY

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t								REMARKS
						LIME	AERO 633	NPSO 20						
CONDITION	10	20	8.50	250g cell	1500	0.6	0.4	0.01%						-poor flotation response
FLOAT	3				1500									-thick, sticky hard to control froth
														- dense bubbles. Carbon present in froth.

PRODUCT	Wt. gr.	Wt. %	ASSAYS				METAL CONTENT				DISTRIBUTION %				REMARKS
			%C	%Mo	%Cu	%Fe					C	Mo	Fe	Cu	
CONC.	27.46	13.58	16.5	23.0	5.25	7.84					19.80	20.52	12.59	12.52	
TAIL	174.76	86.42	10.5	14.0	5.73	8.61					80.20	79.48	87.41	87.48	
TOTAL	202.22	100.0	11.31	15.22	5.67	8.51					100.0	00.0	100.0	100.0	

WITTECK DEVELOPMENT INC. FLOTATION TEST REPORT

SAMPLE: TREATED CONCENTRATE: TESTS# 2, 3 **WEIGHT-GR:** 200 **TEST NO:** AT2

SUBJECT OF TEST: ORE FLOTATION: FLOAT MOLYBDENITE, DEPRESS HYDROCARBON **DATE:** MARCH 27, 1987

TEST BY

OPERATION	Time min.	% Solids	pH	Unit	rpm	Reagents kg/t							REMARKS
						LIME	AERO 633	NPSO 20					
CONDITION	10	20	8.50	250g cell	1500	0.9	0.4	0.01%					-poor flotation response
FLOAT	3				1500								-thick, sticky, hard to control froth
													-small, dense bubbles
													-carbon present in froth

PRODUCT	Wt. gr.	Wt. %	ASSAYS %C	%Mo	%Cu	%Fe	METAL CONTENT				DISTRIBUTION % C	Mo	Cu	Fe	REMARKS
CONC.	54.20	27.45	20.0	20.4	5.05	7.48					43.04	35.34	24.66	24.84	
TAIL	143.26	72.55	10.0	14.1	5.83	8.55					56.96	64.66	75.34	75.16	
TOTAL	197.46	100.0	12.75	15.84	5.62	8.26					100.0	100.0	100.0	100.0	